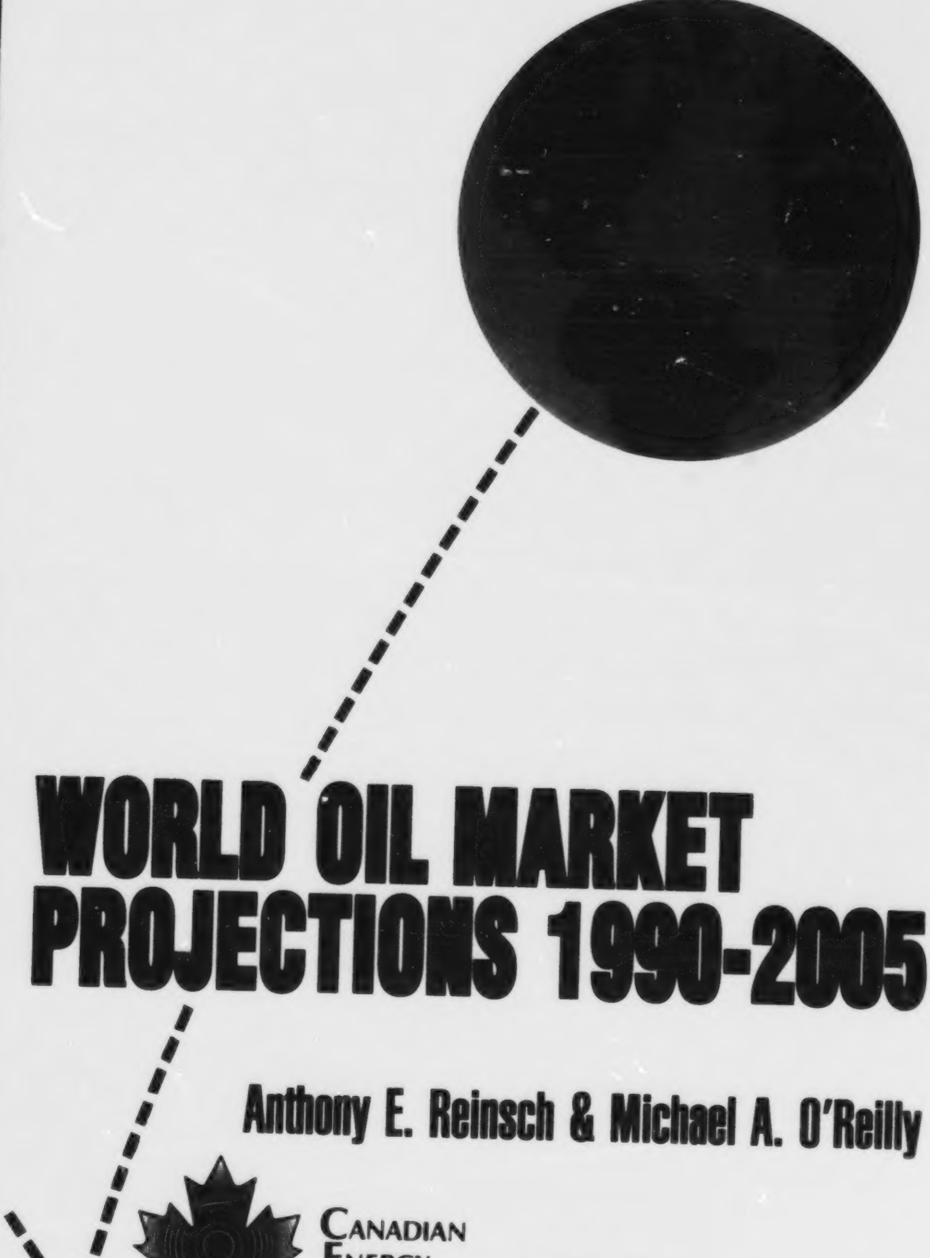

WORLD OIL MARKET PROJECTIONS 1990-2005

Anthony E. Reinsch & Michael A. O'Reilly

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MICHAEL A. O'REILLY

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Preface

The global energy market has responded to the uncertainty of world oil supply and prices through the pursuit of increased energy efficiency and multiple energy sourcing. However, the evolution of the world oil market and the likely path of crude oil prices continue to play a key role in shaping domestic energy policy and energy sector planning. This report is the second in a series of research studies designed to monitor developments in the world oil market, to assess the likely impact of key uncertainties affecting the market, and to provide a reference crude oil price path upon which industry and government can base their investment decisions and policy prescriptions. The Board of Directors of the Canadian Energy Research Institute, through their support of this research program, recognize the important role which crude oil continues to play in the global energy market.

The study authors wish to express their thanks to a number of Institute staff involved in the production of this document: Janice Morrison, who prepared and coordinated the publishing of the final document; Megan Murphy, who created the graphics; and Nancy Sanford, who provided editorial assistance. Special thanks are given to Dr. Gerry Angevine for his useful comments on the final draft, and to Morgan MacRae for his support, advice and encouragement throughout the project.

Special mention is given here to Robert Wise, who contributed greatly to the model development work undertaken over the past year. His insight and effort on behalf of this project were invaluable to the completion of the study, and his contributions will remain an integral part of the CERI World Oil Market Model.

The Institute is undertaking further analysis of the operations of the world oil market and refinements to the analytical framework used to generate the market projections contained in this study. CERI encourages your input and commentary on the contents of this study and suggestions for future research into the evolution of the world oil market.

EXECUTIVE SUMMARY

The world oil market of the 1980s will be remembered as a source of unprecedented instability and uncertainty in the global economy, touching virtually every element of economic and social planning in every part of the world. From the dizzying price levels of the early 1980s--and the unrealistic expectations for continued price gains--to the depths of the 1986 oil price crash, policy-makers and crude oil producers rode the roller-coaster of oil market uncertainty brought on by unexpectedly strong demand response to price and income changes and the success of non-OPEC countries in realizing the oil reserves potential existing outside of the OPEC world. These forces created the surplus capacity overhang which dominated energy sector planning and oil price developments over the last decade.

This study continues the research program on world oil market fundamentals initiated in the release of CERI Study No. 28, *Stability Within Uncertainty: Evolution of the World Oil Market* (September 1988). The centerpiece of the research effort is the CERI World Oil Market Model (WOMM), an integrated supply-demand model capable of generating consistent projections of world oil prices or OPEC production levels under a wide range of plausible assumptions regarding world economic growth, product demand response to oil price and income changes, ultimate potential oil reserves in the non-OPEC producing countries and numerous other critical variables affecting the evolution of the world oil market.

The central message of *Stability Within Uncertainty* was that despite the short-term volatility of world oil market prices and the uncertainty inherent in a market structure dominated by a heterogeneous and fractious producer "cartel," the market remained fundamentally robust across a wide range of potential market shocks. The strength of the supply and demand fundamentals in returning the market to a stable, rising real oil price path was couched in the observation that virtually all of the short-term price risk associated with the world oil market resided on the downside.

The projections provided in this study suggest that the fragility of oil prices, which prompted unusual conservatism in oil sector exploration and development activity in the late 1980s, is likely to dissipate as we move through the 1990s. Slow but steady demand growth for refined petroleum products combined with a gradual decline in non-OPEC production should serve to tighten the supply-demand balance in the world oil market. With the current surplus capacity overhang worked off by the middle of the decade, the market would be poised for real price and/or OPEC production gains, the latter being increasingly concentrated in the Persian Gulf OPEC countries.

Placed against the supply-demand fundamentals are new uncertainties which can be expected to impact the global oil market. Foremost among these are the expected but uncertain actions forthcoming on behalf of the global environment. Concerted actions on a global basis directed toward the reduction of atmospheric and greenhouse gas emissions could result in a replay of the energy conservation, efficiency and off-oil initiatives of the early 1980s, but this time driven by fiscal incentives rather than market-responsive prices.

Elsewhere, the efforts of the developing countries toward industrialization and economic growth are a continuing source of pent-up energy and petroleum products demand. The dramatic political and social changes in Eastern Europe and the Soviet Union could have major impacts on the world energy markets, through both increased energy demand and greater exploitation of the hydrocarbon reserves resident in those regions. Lying behind all of these developments is a growing concern over the financial ability of the OPEC nations to increase productive capacity in order to meet the demand growth anticipated for the latter 1990s and to thereby avoid another high oil price cycle.

Reference Market Projections

The reference case oil market projections provided in Chapter 2 reflect a most-likely development scenario for world oil prices, abstracting from the key uncertainties referenced above. **The principal message arising from this projection is that the world oil market will attain a tighter supply-demand balance by the mid-1990s, reintroducing the potential for engineered real price gains through the latter half of the decade and into the next century**. The reference case oil price path is based on an OPEC strategy of gradual real price and production gains over the forecast period.

Table 1 provides a summary of the reference case results. Given the assumed level of OPEC production, the price trajectory shown in the table represents a readily sustainable path. The

TABLE 1

REFERENCE CASE MARKET SUMMARY
1990-2005

Year	Price ($1989 U.S.)	OPEC Production (MMb/d)	World Demand (MMb/d)	World Supply (MMb/d)	Non-CPE Demand (MMb/d)	Non-CPE Supply (MMb/d)	Net CPE Exports (MMb/d)
1990	20.00	22.0	67.02	67.02	53.03	50.85	2.18
1991	21.00	22.6	67.72	67.72	53.54	51.56	1.98
1992	21.50	23.2	68.45	68.45	54.07	52.24	1.83
1993	21.95	24.0	69.18	69.23	54.60	53.07	1.58
1994	22.30	24.9	69.99	70.00	55.18	53.81	1.38
1995	22.70	25.9	70.82	70.82	55.78	54.59	1.19
1996	23.40	26.9	71.59	71.59	56.30	55.31	1.00
1997	24.10	27.9	72.31	72.31	56.79	56.00	0.79
1998	24.50	29.0	73.11	73.11	57.35	56.76	0.59
1999	25.30	30.1	73.84	73.89	57.85	57.55	0.35
2000	26.10	31.2	74.54	74.54	58.31	58.31	0.00
2001	26.20	32.2	75.40	75.40	58.93	58.93	0.00
2002	27.00	33.2	76.24	76.24	59.52	59.53	0.00
2003	27.65	34.2	77.09	77.09	60.12	60.12	0.00
2004	28.40	35.2	77.93	77.93	60.70	60.70	0.00
2005	29.20	36.2	78.76	78.76	61.28	61.28	0.00

SOURCE: Canadian Energy Research Institute, January 1990.

principal trend is for stable real prices over the early 1990s followed by gradually accelerating price gains into the next century. Prices reach $22.70 per barrel in 1995, $26.10 per barrel in 2000, and rise to $29.20 per barrel by 2005.

In many respects, this reference case projection represents a "best-case" scenario for all oil market players. For OPEC members, the price-production profile allows for steady near-term revenue growth through output quota gains, and longer-term revenue growth through both price and output gains. Annual oil revenue accruing to OPEC more than doubles over the forecast horizon, from $160 billion in 1990 to $386 billion in 2005 (constant $1989 U.S.). In present value terms, OPEC would realize over $2 trillion from crude oil sales over the 15-year period, assuming a 10 percent rate of discount. **This revenue profile is equivalent or superior to the revenue profiles generated under the numerous sensitivity analyses and alternative scenarios generated in this research program, reinforcing the strategic importance of a sustained, gradual price-production growth strategy for OPEC.**

For non-OPEC producing countries, the real price gains through the 1990s are sufficient to justify development of existing established reserves and exploration activity directed to the more promising prospects and plays. However, prices do not reach a level sufficient for development of grassroots frontier and nonconventional crude oil sources (e.g., integrated mined oil sands, two-stage coal liquefaction) until late in the forecast period. For the consumer, real crude oil price increases of 2.0 to 3.5 percent per year do not constitute an important cost-push element to general price inflation. Indeed, these projected price gains are generally below those forecast for other energy commodities (particularly natural gas and electricity) in the industrialized countries over the projection period.

The reference case OPEC production profile contains an implicit assumption that Organization members will be able to increase productive capacity in order to service the rising call on OPEC crude, particularly in the 2000-2005 period. **While there is no argument that OPEC possesses the physical reserves to meet rising world oil demand, there is growing concern that the Organization may lack the financial reserves to undertake the required facilities expansion.** The severe national debt problems facing many OPEC member nations have made the prospect of discretionary fiscal weakness within OPEC a very real concern. One possible outcome arising from this situation is a modest re-integration between the multi-national oil companies and those OPEC members amenable to joint venture capital in the development of domestic reserves.

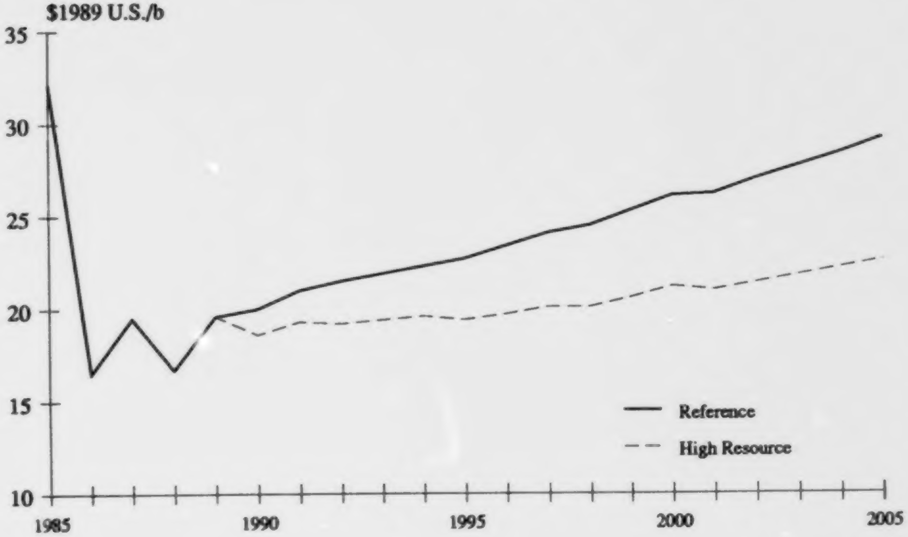
In summary, the reference oil price projection is dependent on continued OPEC production restraint, particularly over the next 4 to 5 years. Beyond the mid-1990s, the combination of steady petroleum product demand growth and declining non-OPEC production turns the world oil market increasingly toward the OPEC nations and, in particular, the reserves-rich Persian Gulf countries. The medium- to long-term benefits awaiting the Organization should outweigh the near-term revenue temptation associated with rapid production or price increases, yielding a market that becomes more stable as we move through the 1990s and into the next century.

Assessing the Uncertainties

Chapter 3 of the study provides a detailed examination of a number of key uncertainties in the world oil market. The high non-OPEC resource scenario examines the impact on the reference case projection of a larger non-OPEC resource base. In this scenario, the ultimate potential for each non-OPEC producing nation is switched to the 5 percent probability level (i.e., optimistic resource base estimate) from the modal estimate which is used in the reference case projections and all other scenarios. All other reference case assumptions, including the projected level of OPEC production, are unchanged.

The results suggest that such a scenario would yield lower crude oil prices over a longer period of time than under the reference case (see Figure 1). For OPEC, this scenario would clearly exacerbate the divisions within the Organization regarding pricing and production strategies. To maintain revenue at the levels associated with the reference case scenario would require greater OPEC production, resulting in much lower prices. To maintain prices at the levels associated with the reference case would require much lower OPEC production, exacerbated by the supply response from the non-OPEC regions. The risk of a crude oil price collapse under this scenario would be much greater than under the reference case, as would the probability of a collapse in the Organization down to a smaller group of nations characterized by large crude oil reserves and the ability to achieve and maintain high production levels.

Figure 1
High Non-OPEC Resource Scenario
World Oil Prices



SOURCE: CERI, January 1990.

The high non-OPEC resource scenario is a legitimate alternative to the reference case projection, whether the high non-OPEC production levels are deemed to be associated with a larger reserves base or with advances in oil sector technology. Continued gains in seismic and drilling technology, which lower the hurdle price for new field development, would tend to accelerate non-OPEC production gains. Advances in enhanced oil recovery techniques--aimed at accessing the roughly 50 to 60 percent of original oil-in-place remaining after exhaustion of primary and secondary drive--and cost reductions in nonconventional oil liquids technologies would further add to non-OPEC productive capacity.

The examination of alternative OPEC price-production strategies concludes that, from a revenue standpoint, the Organization would benefit equally from a near-term price gain or near-term production gain strategy, and that the present value of the resulting revenue streams would be virtually identical to that of the reference projection, at roughly $2.0 trillion (assuming a 10 percent discount rate). **However, the choice of price-production strategy has a very marked impact on the evolution of the world oil market and on the type of market OPEC would face at the start of the next century.** Under a near-term price gain strategy, OPEC would create a market that is growing as we enter the next century. Under a near-term production gain strategy, OPEC would see a market in decline, albeit from a larger size in the 1990s. Under the reference case price-production strategy, the Organization would see a market that is both larger and gradually expanding. **Again, the combination of gradual price and production gains through the next decade would appear to be a dominant OPEC strategy in terms of market share and market size, even if it is revenue neutral in comparison to the alternative price-production strategies.**

Two additional scenarios were examined, dealing with uncertainties which could significantly alter the assumptions underlying the scenarios discussed above. The first dealt with the growing global concern over atmospheric emissions, the second with the dramatic events unfolding in the Soviet Union and Eastern Europe.

Environmental Initiatives

To fully address the question of reduction of atmospheric emissions on a global basis clearly requires a comprehensive energy end-use model, flexible enough to examine the fuel substitution and energy use impacts of a wide range of fiscal and emission guideline options. While the CERI World Oil Market Model falls short of this objective, it is useful in examining the potential impact of the imposition of end-use taxes on petroleum product demand and, hence, on world oil prices.

The scenario examined in Chapter 3 assumed the application of a 10 percent product tax on transportation fuels and heavy fuel oil, levied at the burner tip. The tax was assumed to be phased in across the industrialized countries over the 1990-1995 period.

It was further assumed that for various political, social and financial reasons, no equivalent action would be taken by the developing countries. This reflects the view that the developing countries, still struggling to attain the level of economic wealth achieved by the industrialized countries through, in part, the unfettered exploitation of global hydrocarbon reserves, would not agree to jeopardize their growth potential through reduction in energy use, regardless of the potential consequences of global warming and continued environmental degradation. Rather, the solution to the buildup of greenhouse gas emissions would be left to those nations that had benefitted from the creation of the problem.

The key scenario result is that national and regional initiatives to reduce oil product consumption, for environmental or other reasons, will not be successful unless all nations are involved in the process. Gains made in one jurisdiction in reducing petroleum product demand will show up, through the oil market, as price-driven incentives to increase petroleum product consumption in other regions. **In the absence of global cooperation, such a piecemeal approach to the reduction of hydrocarbon consumption would have little impact beyond generating considerable revenue to those governments pursuing such fiscal initiatives, and transferring a cost of production and terms of trade advantage to those who chose not to implement those initiatives.**

Soviet Union and Eastern Europe

The social, political and economic upheaval currently ongoing in the Soviet Union and Eastern Europe is destined to have profound implications for every facet of the global community, including the world energy markets. Analysis of the potential impact of glasnost and perestroika on Soviet and Eastern European economic developments, on energy demand and supply, and on the net crude oil export position of the CPEs in the world oil market is further complicated by the directional uncertainty of these developments in affecting the world oil market.

On the demand side, support from the industrialized countries through, for example, the provision of financial and human capital to support accelerated industrialization of the Soviet Union and Eastern European economies would lead to stronger energy (and petroleum product) demand growth than envisaged under the reference case. Deployment of older production processes and technologies, which tend to be more energy intensive, would reinforce this demand profile. On the supply side, outside involvement in the development of Soviet energy resources--particularly in the form of imported technology--could accelerate significantly the crude oil production and export capability of the Soviet Union.

The scenario examined in Chapter 3 is only one of many possible outcomes resulting from this unprecedented political upheaval. As events unfold, it will become possible to better gauge the magnitude of competing forces impacting the energy sector in these countries. It is clear, however, that careful research and analysis must be directed towards a better understanding of the supply-demand fundamentals underlying the energy sectors of the centrally planned economies.

Future Research

The Canadian Energy Research Institute has in place an ongoing research program directed towards the refinement and enhancement of the World Oil Market Model and the identification and analysis of key variables impacting on the evolution of the world oil market. To date, the majority of research effort has been directed towards the disaggregated representation of non-OPEC producing countries within the WOMM.

Over the next twelve months, the research effort will focus on the demand side of the oil market, further disaggregating the regional assessment of petroleum product demand and investigating the incorporation of explicit interfuel substitution capabilities within the framework. A separate research agenda will focus on developments in the Soviet Union and Eastern Europe, with the objective of incorporating the findings into the WOMM.

The enhanced WOMM framework will be employed in preparing the third in the CERI series of world oil market studies, scheduled for June 1991. Users of the World Oil Market Model and other interested parties are encouraged to forward their comments and input regarding the WOMM and world oil research programs to the Institute.

Chapter 1

INTRODUCTION

1.1 Stability Within Uncertainty

In the fall of 1988, the Canadian Energy Research Institute (CERI) released a comprehensive study of the fundamental supply and demand characteristics underlying the world oil market, entitled *Stability Within Uncertainty: Evolution of the World Oil Market* (CERI Study 28). That study, initiated after the oil price crash of 1986, focussed on the key determinants of world refined petroleum product demand and non-OPEC crude oil supply. The centerpiece of the research effort was the development of the CERI World Oil Market Model (WOMM), an integrated supply-demand model capable of generating consistent projections of oil prices or OPEC production levels under a wide range of plausible assumptions regarding world economic growth, product demand response to oil price and income changes, ultimate potential oil reserves in the 16 non-OPEC producing regions addressed in the model, and numerous other critical factors affecting the evolution of the world oil market.

The central message of *Stability Within Uncertainty* was that despite the short-term volatility of world oil market prices and the uncertainty inherent in a market structure dominated by a heterogeneous and fractious producer "cartel," the market remained fundamentally robust. Regardless of the severity of supply and demand side shocks placed on the market, the strength of the supply and demand fundamentals returned the market to a stable, rising real oil price path. This gradual rise in real oil prices was predicated on steady growth in crude oil demand (particularly in the nations comprising the Organization of Petroleum Exporting Countries (OPEC) and the less developed countries, or LDCs), the inexorable decline in non-OPEC production (centred in particular in the United States and, later in the 1990s, the North Sea), and a reasonable degree of cohesive OPEC behaviour with regard to production levels and price targets.

The second key message to oil market players was that virtually all of the short-term price risk associated with the world oil market resided on the downside. Efforts by OPEC to capture short-term price gains through greater production restraint would be met by renewed non-OPEC development activity and reductions in product demand growth. Once brought into production, very little non-OPEC production would be shut-in even at prices below $10 (U.S.) per barrel. Therefore, on the supply side, a high-price, low-volume market strategy by OPEC carried the risk of stimulating long-term non-OPEC production gains (regardless of subsequent OPEC market manipulations) and, correspondingly, minimizing the market share and revenue gains being sought by the OPEC producers.

The second edge to this sword rested on the demand response to a high oil price scenario. Having adjusted to the oil price shocks of 1973-1974 and 1979-1980, the industrialized world was more capable of responding to relative price movements in the energy markets. High oil prices would generate a movement away from refined petroleum product consumption, particularly in the heavier product categories where dual- and triple-fuel combustion technologies were gradually enhancing the flexibility of industrial sector energy demand. More worrisome to OPEC was the increase over time in the responsiveness of oil demand to price changes. New capital investment, particularly in Western Europe and the Pacific Rim, was not only less energy intensive than the capital stock it was replacing, but was also less oil intensive, either through fuel flexibility or, increasingly, through dedication to electricity as the source of motive power. Thus each new upward price shock now carried the risk of permanent market loss for oil products, and reinforced the psychological (as well as economic) desire of consumers to reduce exposure to the volatility of the world oil market.

The combination of non-OPEC production gains and a negative oil demand response would require OPEC to continually tighten production controls in order to maintain a high-price market strategy. The resulting loss in both market share and revenue, relative to a gradual price and volume growth strategy, argued strongly against the scenario of a third upward price shock.

The possibility of OPEC overproduction aimed at lowering crude oil prices, perhaps in an attempt to destabilize the non-OPEC producers and to re-establish refined petroleum product markets, was similarly ruled out as an uneconomic market strategy on the part of OPEC. The resilience of non-OPEC production to low crude oil prices, reflected in the World Oil Market Model and evidenced in the price crash of 1986, negated the incremental market share gains that a low-price, high-volume market strategy would be designed to generate for

OPEC. Clearly, the impact of low oil prices was felt in curtailed exploration and development activity in the non-OPEC producing countries (which would not impact productive capacity in the near term), but not in any meaningful curtailment of crude oil production. Therefore, even though demand growth resulted in a larger world oil market pie, the growth in market share accruing to OPEC was insufficient to offset the low price environment being created. Again, from a revenue standpoint, a low-price, high-volume strategy was shown to be clearly inferior to a gradual price and volume growth strategy.

These key results--gradually strengthening real crude oil prices and the presence of considerable downside price risk--formed the principal message arising from *Stability Within Uncertainty*. The present study extends the 1988 World Oil Market Model projections into the next century, provides a revised reference case scenario for world oil prices, and examines a set of alternative scenarios which provide further insight into the likely issues and forces which will dominate oil market developments into the next century.

1.2 Study Organization

The study is organized as follows. Chapter 2 provides a detailed assessment of the reference case world oil market projections to the year 2005. The reference case is compared with that contained in *Stability Within Uncertainty*, highlighting the similarities and differences between the two scenarios.

Chapter 3 discusses the alternative scenarios which have been selected for this study. These scenarios focus on particular issues or questions which the study authors believe will play a prominent role in world oil market developments through the 1990s. Finally, Chapter 4 provides a summary of key conclusions and observations stemming from these analyses.

Appendix A to this study provides a brief description of the CERI World Oil Market Model and enhancements to the framework since the release of *Stability Within Uncertainty*. For a detailed discussion of the model development and structure, the reader is referred to the earlier study. Appendix B provides the regional economic growth assumptions underlying the reference case projection. Appendices C and D contain detailed demand and supply tables, respectively, extracted from the reference case scenario discussed in Chapter 2. Appendix E provides summary tables taken from the alternative scenarios examined in this study.

Chapter 2

REFERENCE PRICE PROJECTION: 1990-2005

2.1 Introduction

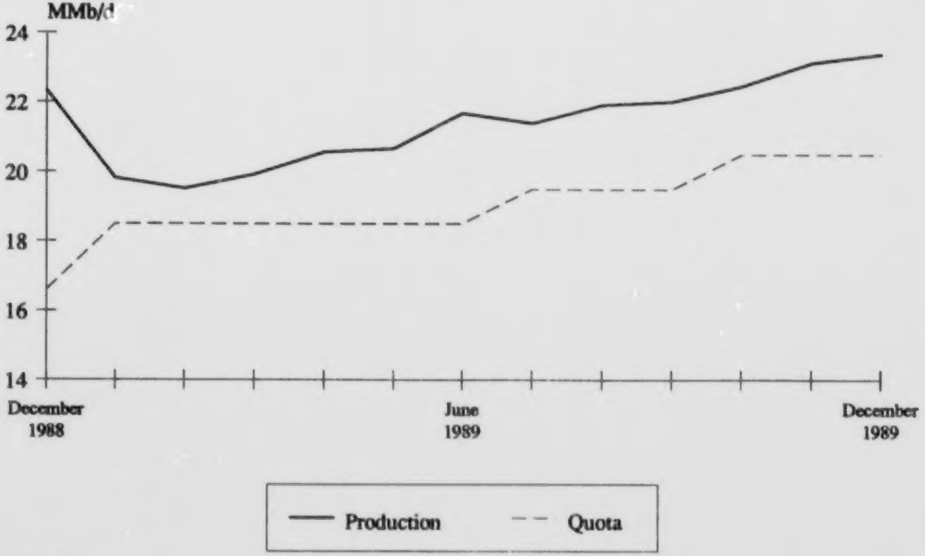
Developments in the world oil market since the summer of 1988 have served to underline the importance of market fundamentals in assessing the likely future path of oil prices. The second half of 1988 was characterized by chronic OPEC overproduction relative to assigned quotas (see Figure 2.1) and crude oil spot prices which languished in the $13 to $15 (U.S.) per barrel range (see Figure 2.2). Budget decisions for the 1989 drilling season reflected this fundamental supply-demand equilibrium, with $15 per barrel being used as the consensus hurdle price for exploration plays and project development.

Movements by OPEC to address this situation resulted in a new production and pricing accord in November 1988 and a concerted effort by Organization members to operate within the terms of the accord. The new accord called for an OPEC production quota of 18.5 MMb/d, to be applied to marketed crude oil volumes rather than production, and the acceptance of a target price of $18.00 (U.S.) per barrel for the OPEC basket of crudes. The accord also called for regular, 6-month re-evaluations of the quota volume and served notice that discussions would take place to reassess the methodology used to allocate the production quota among member nations.[1]

The dramatic cutback in OPEC production in the first two months of 1989 reinforced the general market optimism accompanying the new production agreement. Spot prices responded accordingly, with West Texas Intermediate (WTI) crude prices moving in the $17 to $18 (U.S.) per barrel range. Indeed, the response of OPEC following the November 1988 agreement spoke volumes for the ability of the member countries to act as a producer cartel, given sufficient incentive to do so.

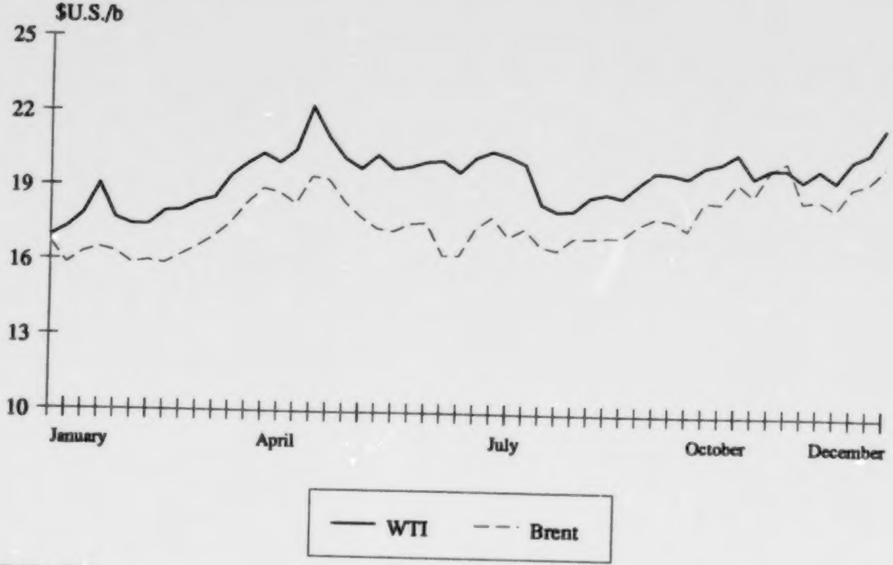
Continued OPEC production restraint may, in fact, have been able to overcome the second quarter price weakness then projected for 1989; however, events elsewhere turned the attention of market watchers away from OPEC to developments in the non-OPEC world. First, and most important, was the wreck of the Exxon Valdez

Figure 2.1
OPEC Crude Oil Production and Quotas
December 1988 - December 1989



SOURCE: PIW.

Figure 2.2
Selected Crude Oil Spot Prices
January - December 1989



SOURCE: CERL

oil tanker in Prince William Sound off the coast of Alaska.[2] The immediate impact of this disaster--the disruption of shipments to the Lower-48 states from the port of Valdez and reduction in deliveries from the Prodhoe Bay-Valdez pipeline--caused spot prices for WTI to break the $20 (U.S.) per barrel level. The longer-term implications will be felt, likely for years to come, through the focussing of attention on the environmental risks associated with tanker transport of crude oil and, more generally, the development of crude oil projects in environmentally sensitive areas.

Non-OPEC production volumes received a second setback with the natural gas explosion on the Cormorant Alpha platform in the North Sea in late April, shutting in some 450,000 barrels per day of Brent crude production.[3] Combined with the Valdez incident and production difficulties in Colombia, where guerilla attacks slowed production through the second quarter, total non-OPEC production was some 2.0 MMb/d below expectations in the second quarter of 1989, allowing OPEC the luxury of increasing production over quota and reaping the benefits of higher-than-expected prices.

On the demand side of the oil market equation, the oil price weakness of 1986-1988 and continued economic expansion in the industrialized countries and in a number of developing countries led to strong demand growth in the first half of 1989. With net demand for OPEC crude estimated to be in the 21.5 to 22.0 MMb/d range, the Organization moved quickly to meet this strong demand by increasing quotas, first to 19.5 MMb/d in July 1989, to 20.5 MMb/d in October 1989, and most recently to 22.0 MMb/d for the first half of 1990.[4]

The transient nature of the market factors which buoyed crude oil prices through the second and third quarters of 1989--non-OPEC production setbacks, weather-related heating oil demand strength in the OECD countries, inventory builds in Japan prior to the imposition of crude oil import tax hikes--have not been lost on oil market participants. Investment intentions for 1990 by North American and multi-national oil companies are up only about 10 percent from the weak performance of 1989, as the supply-demand imbalance underlying the oil market continues to call for caution in the face of significant downside price risk.[5] Price expectations for WTI appear to reside in the $17 to $18 (U.S.) per barrel range, rather than the $20 to $21 per barrel range in which spot prices have moved over the past 6 months. The rapid ascendence of environmental concerns to the forefront of the social and political conscience has introduced new uncertainties into the planning horizon of energy market players.

The following section provides a detailed analysis of the reference price projection for WTI for the period 1990-2005. It is termed a "reference" projection because it embodies a reasonable set of assumptions regarding OPEC production levels over time, non-OPEC supply potential, GDP growth around the world, and the responsiveness of oil demand to changes in the oil price and economic growth rates.

The reference price projections were generated using the price simulation mode of the CERI World Oil Market Model and hence the reported prices and volumes represent annual average "market clearing" levels. All prices are tied to West Texas Intermediate crude at Cushing, Oklahoma, expressed in constant 1989 U.S. dollars per barrel. Quality adjustments and transportation netback calculations can be employed to generate price equivalents for other crudes.

2.2 Reference Price Projection

Table 2.1 provides a summary of some key indicators of world oil supply and demand over the last 4 years, to serve as a benchmark for comparison with the reference case results. The salient pieces of information contained in the table are:

- OECD oil consumption will record its fourth consecutive year of positive growth, up by a projected 300 Mb/d in 1989 over 1988 and by just under 3.0 MMb/d over 1985.[6]

- Consumption gains in the developing countries (LDCs) are projected to exceed those in the developed countries (OECD) in 1989, rising 600 Mb/d over 1988. Developing country oil demand in 1989 is more than 2.0 MMb/d above that recorded in 1985.

- As a whole, non-CPE oil consumption grew by a projected 1.8 percent in 1989 over 1988, increasing from 50.9 MMb/d to 51.8 MMb/d. Projected figures for 1989 show a 5.0 MMb/d gain in consumption (10.7 percent) over the 1985-1989 period, yielding an average annual growth rate of 2.7 percent.

- Year-over-year production of total non-OPEC crude oil liquids is expected to show a decline of some 400 Mb/d, on average, in 1989 compared to 1988. This is due to the production setbacks experienced in the first 8 months of the year. Fourth quarter 1989 production

TABLE 2.1

WORLD OIL SUPPLY AND DEMAND
1986-1989
(MMb/d)

	Consumption			Supply							
Year	OECD	Non-OECD	Total World[a]	OECD	LDCs	Net CPE Exports	Total Non-OPEC[b]	OPEC Crude Production	OPEC NGL Production	Total OPEC	Total World[a]
1985	34.4	12.4	46.8	17.0	8.6	1.9	28.6	16.0	1.5	17.5	46.1
1986	35.4	12.8	48.2	16.8	8.6	2.0	28.5	18.0	1.8	19.8	48.3
1987	36.0	13.3	49.3	16.8	9.0	2.1	29.0	17.7	1.8	19.6	48.6
1988	37.0	13.9	50.9	16.6	9.3	2.2	29.2	19.7	1.8	21.6	50.8
Q1	37.7	13.9	51.5	17.1	9.3	1.8	29.3	17.8	1.8	19.6	48.9
Q2	35.1	13.4	48.5	16.7	9.3	2.4	29.4	18.8	1.8	20.6	50.0
Q3	36.2	13.9	50.1	16.3	9.2	2.4	29.1	20.0	1.9	21.8	51.0
Q4	39.1	14.3	53.4	16.4	9.4	2.2	29.1	22.3	1.9	24.2	53.3
1989[c]	37.3	14.5	51.8	16.0	9.6	2.1	28.8	21.6	1.9	23.5	52.3
Q1	38.3	14.5	52.8	16.1	9.5	1.9	28.6	19.9	1.9	21.8	50.4
Q2	35.8	14.0	49.8	15.8	9.4	2.2	28.4	21.1	1.9	23.0	51.4
Q3	36.3	14.5	50.8	15.8	9.6	2.2	28.7	22.1	1.9	24.0	52.7
Q4 (P)	38.8	14.9	53.7	16.3	9.8	2.2	29.5	23.3	1.9	25.1	54.6

SOURCE: International Energy Agency, *Oil Market Report*, December 1989.

[a] Excludes centrally planned economies (CPEs).
[b] Includes 1.1 MMb/d for refinery gain.
[c] Projected annual figures for 1989.

volumes are projected to exceed fourth quarter 1988 levels by 400 Mb/d.[7]

- OPEC crude oil production levels in 1989 are significantly higher than 1988 levels, showing a gain of 1.9 MMb/d or 9.6 percent. Projected 1989 average production of 21.6 MMb/d is 5.6 MMb/d above that recorded in 1985.

As discussed above, the combination of steady demand growth and non-OPEC production setbacks allowed for average WTI prices in 1989 to reach $19.58 (U.S.) per barrel, just below the current dollar price of $20.05 projected in CERI Study No. 28, *Stability Within Uncertainty*.

With this backdrop in mind, the most crucial assumption required to project future prices--the level of OPEC production over the forecast horizon--is provided in Table 2.2. Between 1990 and 1992, the ability of OPEC to increase production, while protecting an acceptable market price, is assumed to be mitigated by increases in non-OPEC production.[8] During this period, OPEC production increases by 2.7 percent per year. After 1992, the gradual decline in non-OPEC production and slow but steady product demand growth allow for more aggressive OPEC production gains, averaging over 4.0 percent per year. By the year 2000, OPEC crude oil production reaches 31.2 MMb/d, a level that is 44 percent above the annual daily average production level in 1989 and almost 90 percent of estimated current productive capacity of 34.0 MMb/d for the Organization.[9]

Production gains on the part of the Organization are assumed to decline, in percentage terms, through the late 1990s and into the next century as OPEC strategy shifts to price gains. Implicit in the 2005 production figure of 32.6 MMb/d is an assumed increase in productive capacity, centered in Venezuela and the reserves-rich Persian Gulf nations of Saudi Arabia, Kuwait, the United Arab Emirates (U.A.E.) and Qatar (sometimes referred to as the Gulf OPEC or "GOPEC" nations).

Table 2.3 provides a summary of the reference case results. Given the assumed level of OPEC production, the price trajectory shown in the table represents a readily sustainable path. The principal trend is for stable real prices over the early 1990s followed by gradually accelerating price gains into the next century. Prices reach $22.70 per barrel in 1995, $26.10 per barrel in 2000, and rise to $29.20 per barrel by 2005.

TABLE 2.2

REFERENCE CASE OPEC PRODUCTION
1989-2005

Year	Annual Daily Average (MMb/d)	Annual Change (%)
1989	21.6	1.9
1990	22.0	2.7
1991	22.6	2.7
1992	23.2	2.7
1993	24.0	3.4
1994	24.9	3.8
1995	25.9	4.0
1996	26.9	3.7
1997	27.9	3.9
1998	29.0	3.8
1999	30.1	3.7
2000	31.2	3.2
2001	32.2	3.1
2002	33.2	3.0
2003	34.2	2.9
2004	35.2	2.9
2005	36.2	2.8

SOURCE: Canadian Energy Research Institute, January 1990.

TABLE 2.3

REFERENCE CASE MARKET SUMMARY
1990-2005

Year	Price ($1989 U.S.)	World Demand (MMb/d)	World Supply (MMb/d)	Non-CPE Demand (MMb/d)	Non-CPE Supply (MMb/d)	Net CPE Exports (MMb/d)
1990	20.00	67.02	67.02	53.03	50.85	2.18
1991	21.00	67.72	67.72	53.54	51.56	1.98
1992	21.50	68.45	68.45	54.07	52.24	1.83
1993	21.95	69.18	69.23	54.60	53.07	1.58
1994	22.30	69.99	70.00	55.18	53.81	1.38
1995	22.70	70.82	70.82	55.78	54.59	1.19
1996	23.40	71.59	71.59	56.30	55.31	1.00
1997	24.10	72.31	72.31	56.79	56.00	0.79
1998	24.50	73.11	73.11	57.35	56.76	0.59
1999	25.30	73.84	73.89	57.85	57.55	0.35
2000	26.10	74.54	74.54	58.31	58.31	0.00
2001	26.20	75.40	75.40	58.93	58.93	0.00
2002	27.00	76.24	76.24	59.52	59.53	0.00
2003	27.65	77.09	77.09	60.12	60.12	0.00
2004	28.40	77.93	77.93	60.70	60.70	0.00
2005	29.20	78.76	78.76	61.28	61.28	0.00

SOURCE: Canadian Energy Research Institute, January 1990.

2.2.1 World Oil Demand Projection

World oil demand is projected to exceed 74 MMb/d by the year 2000 and to break 78 MMb/d by 2005. This represents a 16 percent increase over projected 1990 demand of 67 MMb/d. Demand growth by refined product category is provided in Table 2.4. Gasoline exhibits the strongest demand growth, averaging about 1.9 percent per annum over the forecast period. This is due to a lack of viable alternative fuels and to lower rates of product price gains relative to the other product categories. A given increase in the crude oil price translates into a smaller end-product price increase for gasoline than for the other refined petroleum products, due to the higher share of end-product price accounted for by taxes and refining costs. Heavy fuel oil consumption shows only modest gains over the forecast period, ranging between 12.8 and 13.8 MMb/d. This reflects the vigorous interfuel competition being faced through the 1990s from natural gas, electricity and coal. Acceleration in heavy fuel oil demand in the 2000-2005 period reflects the gains in product demand in the developing countries, where dual- and triple-fuel combustion technologies will be slower to penetrate the end-use markets.

On a regional basis (see Table 2.5), OPEC and the developing countries contribute the largest share to world demand growth, with oil consumption projected to increase at an average rate of 4.0 and 1.9 percent per annum, respectively. Consumption in the CPEs is also projected to grow quite vigorously at an average rate of 1.2 percent per annum. A more modest growth rate of 0.5 percent per annum is projected for the OECD countries, led by U.S. gasoline consumption which increases by over 1.9 MMb/d over the forecast period, to 9.9 MMb/d. Of the 11.7 MMb/d increase in world oil consumption projected to occur by 2005, OPEC and the developing countries contribute 2.5 and 2.8 MMb/d respectively, the CPEs contribute another 3.5 MMb/d, while the combined OECD countries add only 2.9 MMb/d. The OECD share of total world oil consumption is correspondingly lower, at 53.3 percent in 2005 versus 58.3 percent in 1990.

2.2.2 World Oil Supply Projection

World crude oil and NGL production is summarized in Table 2.6. As discussed above, OPEC production is assumed to increase from 22.0 MMb/d in 1990 to 36.2 MMb/d in 2005. NGL production associated with this crude oil output profile increases from 1.8 MMb/d in 1990 to 3.1 MMb/d in 2005.

TABLE 2.4

WORLD OIL DEMAND BY PRODUCT
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillates	Heavy Fuel Oil	Other	Total Crude Oil
1990	18,068	21,802	12,878	14,267	67,017
1991	18,480	21,955	12,854	14,433	67,723
1992	18,878	22,111	12,856	14,608	68,452
1993	19,260	22,268	12,872	14,786	69,184
1994	19,640	22,451	12,920	14,977	69,986
1995	20,013	22,648	12,985	15,174	70,823
1996	20,366	22,822	13,033	15,368	71,589
1997	20,699	22,986	13,076	15,554	72,314
1998	21,033	23,181	13,148	15,746	73,110
1999	21,346	23,358	13,207	15,928	73,841
2000	21,642	23,528	13,264	16,107	74,539
2001	21,958	23,766	13,375	16,303	75,400
2002	22,278	23,992	13,466	16,503	76,240
2003	22,604	24,223	13,557	16,708	77,092
2004	22,927	24,448	13,641	16,911	77,927
2005	23,246	24,675	13,728	17,113	78,761

SOURCE: Canadian Energy Research Institute, January 1990.

TABLE 2.5

WORLD OIL DEMAND BY REGION
1990-2005
(Mb/d)

Year	Canada	United States	Western Europe	Pacific OECD	Less Developed Countries	OPEC	Centrally Planned Economies	Total World
1990	1,620	18,425	13,447	5,573	9,817	4,145	13,990	67,017
1991	1,632	18,651	13,497	5,625	9,885	4,253	14,179	67,723
1992	1,646	18,859	13,543	5,682	9,972	4,371	14,379	68,452
1993	1,659	19,045	13,583	5,740	10,080	4,499	14,580	69,184
1994	1,675	19,229	13,628	5,801	10,211	4,637	14,806	69,986
1995	1,691	19,401	13,673	5,865	10,364	4,787	15,041	70,823
1996	1,705	19,530	13,690	5,914	10,524	4,941	15,285	71,589
1997	1,718	19,631	13,692	5,955	10,698	5,101	15,520	72,314
1998	1,733	19,741	13,709	5,998	10,901	5,273	15,756	73,110
1999	1,744	19,813	13,704	6,031	11,114	5,446	15,989	73,841
2000	1,755	19,857	13,684	6,054	11,338	5,625	16,225	74,539
2001	1,772	19,941	13,703	6,093	11,607	5,816	16,468	75,400
2002	1,788	20,015	13,713	6,132	11,862	6,012	16,718	76,240
2003	1,802	20,088	13,724	6,171	12,117	6,216	16,972	77,092
2004	1,816	20,151	13,727	6,208	12,375	6,426	17,224	77,927
2005	1,830	20,202	13,727	6,243	12,640	6,641	17,478	78,761

SOURCE: Canadian Energy Research Institute, January 1990.

TABLE 2.6

WORLD CRUDE OIL PRODUCTION SUMMARY
1990-2005
(Mb/d)

Year	Total	OPEC		CPE	Non-OPEC		Total Non-OPEC Liquids Production
		Crude Oil	NGLs		Crude Oil	NGLs	
1990	67,017	22,000	1,832	16,170	23,097	2,818	25,915
1991	67,723	22,600	1,898	16,160	23,171	2,794	25,965
1992	68,452	23,200	1,966	16,210	23,208	2,768	25,976
1993	69,228	24,000	2,037	16,160	23,193	2,738	25,931
1994	70,002	24,900	2,111	16,190	23,013	2,688	25,701
1995	70,823	25,900	2,187	16,230	22,766	2,640	25,406
1996	71,589	26,900	2,266	16,280	22,449	2,594	25,043
1997	72,315	27,900	2,348	16,310	22,105	2,551	24,657
1998	73,110	29,000	2,433	16,350	21,718	2,509	24,227
1999	73,892	30,100	2,521	16,340	21,364	2,467	23,831
2000	74,539	31,200	2,612	16,228	20,972	2,427	23,399
2001	75,400	32,200	2,706	16,469	20,550	2,375	22,925
2002	76,240	33,200	2,804	16,714	20,099	2,324	22,423
2003	77,092	34.200	2,905	16,971	19,641	2,275	21,916
2004	77,927	35,200	3,010	17,226	19,165	2,227	21,392
2005	78,761	36,200	3,118	17,483	18,679	2,181	20,860

SOURCE: Canadian Energy Research Institute, January 1990.

Projections for the non-OPEC oil producing countries (excluding CPEs) are based on the assumption that they produce at productive capacity unless the price is sufficiently low to justify shutting-in of production, which does not occur in this case.[10] A detailed discussion of the methodology underlying these projections is provided in Appendix A. Country-specific information on projected drilling activity, finding rates, reserves additions and production is provided in Appendix D.

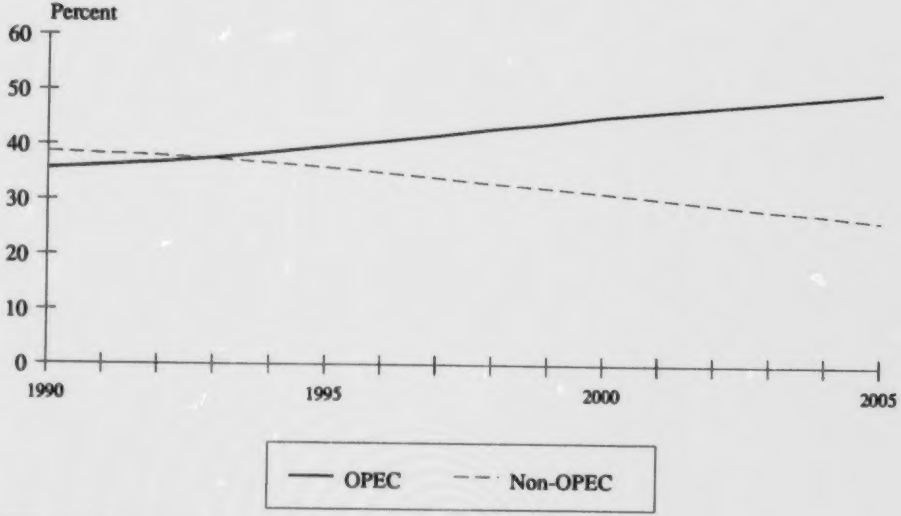
Combined crude oil production in the non-OPEC, non-CPE countries is projected to average 23.1 MMb/d in 1990. Production peaks in 1992-1993 at 23.2 MMb/d and declines throughout the remainder of the forecast horizon, falling to 21.0 MMb/d by 2000 and to 18.7 MMb/d by 2005. Total non-OPEC NGL production declines gradually through the forecast period, from 2.8 MMb/d in 1990 to 2.2 MMb/d in 2005. The share of total non-OPEC, non-CPE crude oil liquids production in total world oil liquids supply therefore declines from 38.7 percent in 1990 to 26.5 percent by 2005. The share of total world oil liquids production accruing to OPEC increases from 35.6 percent in 1990 to 50.0 percent by 2005 (see Figure 2.3).

As shown in the detailed tables in Appendix D, one of the more worrisome results from a political and security standpoint is the decline in OECD crude oil production, from 16.0 MMb/d in 1990 to 11.3 MMb/d in 2005. The decline is centered in the United States and the North Sea, where production declines by 25 percent and 41 percent, respectively, over the forecast horizon. North Sea production actually shows continued growth into the mid-1990s, but the production fall-off after 2000 is steep.[11] Canadian crude oil production is projected to decline by 28 percent over the same period. The decline would be much steeper without the initiation of East Coast offshore frontier production in the late 1990s.

Partially offsetting this decline in OECD production are gains in output from the non-OPEC developing countries (LDCs). Total LDC oil liquids production increases from 9.9 MMb/d in 1990 to 10.3 MMb/d in 2000, followed by a gradual downturn to 9.5 MMb/d in 2005. The bulk of the production gains are provided by Mexico, North and South Yemen, Malaysia, Brazil and Colombia.[12]

Production in the Centrally Planned Economies (CPEs) is assumed to increase gradually over the forecast horizon, from 16.2 MMb/d in 1990 to 17.5 MMb/d in 2005. It should be noted, however, that this production profile is consistent with net CPE exports

Figure 2.3
World Oil Production Shares
1990 - 2005



SOURCE: CERI, January 1990.
NOTE: Share of total production including CPEs.

declining to zero by 2000 and remaining at that level through 2005. This assumes that the Soviet Union is successful in meeting its domestic production targets and, in particular, that the transition to natural gas for industrial applications is continued.

The events which have taken place in the Soviet Union and Eastern Europe further cloud the uncertain future facing this region. Clearly, competing forces are at work in determining the demand for, and supply of, crude oil. If the economic growth initiatives underlying perestroika are successful, this may eventually be accompanied by accelerated growth in energy demand. If the United States and Western Europe choose to provide significant aid to Eastern Europe (both financial and technological) to support the move to democracy in those countries, this will further reinforce the growth in energy demand.[13] On the supply side, an infusion of venture capital and technology from the western world into the energy-producing sector of the Soviet economy could realize tremendous gains in hydrocarbon production.

At this point in time, the forces promoting increased energy and petroleum product demand growth would seem likely to outweigh those promoting increased oil supply over the next decade. Therefore, one might anticipate a more rapid decline in CPE net exports and the potential development of significant crude oil and product imports, particularly into Eastern Europe. Such a development would serve to strengthen world oil prices and provide additional market growth for OPEC production.

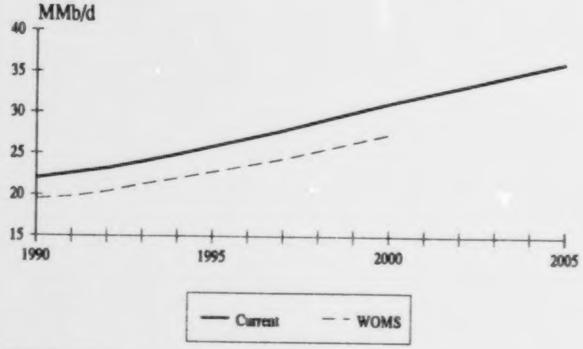
2.3 Comparison with Previous Projections

This section provides a brief comparison of the reference projection discussed in Section 2.2 with the reference case contained in CERI Study No. 28, *Stability Within Uncertainty: Evolution of the World Oil Market* (hereafter referred to as the World Oil Market Study, or WOMS). To allow for ready comparison, the reference case price projections from WOMS have been recalibrated to $1989 U.S. using a 4 percent annual adjustment factor to correct for general price inflation.

2.3.1 OPEC Production

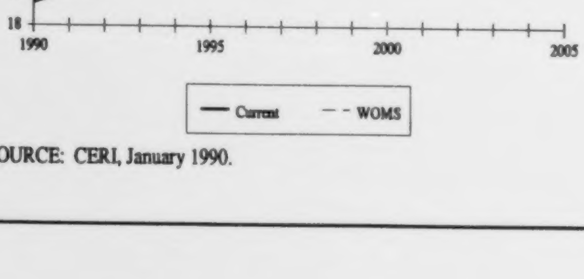
The key assumption underlying the respective reference case projections--OPEC crude oil production over time--is shown in Figure 2.4. The current reference case OPEC production path begins

Figure 2.4
Comparison of Reference Case OPEC Production Volumes, 1990 - 2005



SOURCE: CERI, January 1990.

Figure 2.5
Comparison of Reference Case Oil Price Projections, 1990 - 2005



SOURCE: CERI, January 1990.

at a level that is 2.5 MMb/d above that projected for 1990 in WOMS. This reflects the demand growth experienced since the summer of 1988 which has been somewhat greater than anticipated, the supply setbacks which have slowed non-OPEC production gains over the past year, and the recent OPEC price-production agreement which calls for a first-half 1990 production quota of 22.0 MMb/d. The subsequent growth rates of OPEC production are fairly similar, averaging 4.0 and 4.2 percent per year over the 1990-2000 period in the WOMS and current reference cases, respectively. Since the current reference case is growing from a higher base, the differential between the two OPEC production paths gradually widens, reaching 3.8 MMb/d by the year 2000.

2.3.2 Crude Oil Prices

The crude oil price paths generated in the two reference cases are shown in Figure 2.5. The price projection contained in the WOMS reference case is clearly more aggressive than that provided in the current reference case. The WOMS price track, adjusted to $1989 U.S., rises from $21 per barrel in 1990 to over $29 per barrel by 2000, exceeding the new reference price by $3 per barrel.

The majority of this price differential can be credited to the higher OPEC production path assumed in the current reference case. All else being equal, a higher OPEC production path will tend to dampen real price growth in the market.

2.3.3 Non-OPEC Production

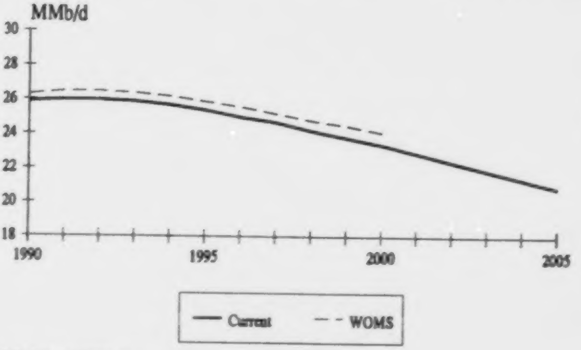
Non-OPEC liquids production volumes are compared in Figure 2.6. Under the current reference case, non-OPEC production peaks at a lower level (26.0 MMb/d versus 26.5 MMb/d) and declines faster than in the WOMS reference case. Part of this result can be attributed to the lower oil price path in the current reference case, which tends to depress drilling activity and hence reserves additions and production relative to a higher price scenario, and part to respecification of the finding rate algorithms and selected ultimate potential estimates embedded within the World Oil Market Model.

2.3.4 World Oil Consumption

World oil consumption volumes are compared in Figure 2.7. As one would expect, the lower price trajectory in the current reference case stimulates refined petroleum product demand. World oil

Figure 2.6

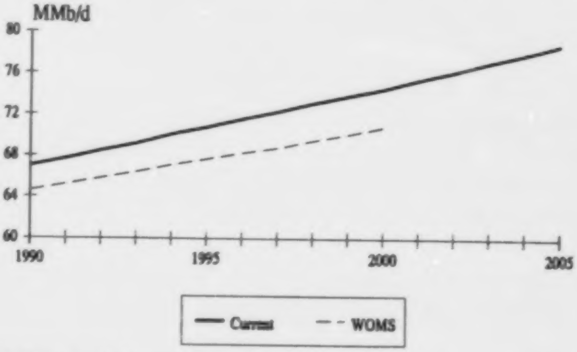
Comparison of Reference Case Non-OPEC Oil Liquids Production, 1990 - 2005



SOURCE: CERI, January 1990.

Figure 2.7

Comparison of Reference Case Oil Consumption Volumes, 1990 - 2005



SOURCE: CERI, January 1990.

consumption in 2000 is 3.7 MMb/d higher under the current reference case relative to the WOMS reference case.

In summary, the combination of higher OPEC production, higher world oil consumption and lower non-OPEC production results in a lower reference case price path than that provided in the WOMS reference case.

2.4 Conclusions and Observations

A critical element of any projected oil market scenario is the implication for OPEC revenue. In the discussion of alternative scenarios in Chapter 3, comparison of OPEC revenue relative to the reference case will be used as a "rationality test" for determining the likelihood of a particular OPEC price-production strategy being adopted.

The implications that the reference case holds for OPEC revenues are outlined in Tables 2.7 and 2.8. The annual revenue stream to OPEC is calculated by multiplying projected prices by the level of OPEC production, ignoring any differences in the actual prices which the various member countries would receive due to differentials in crude quality and transportation costs. The revenue figures should therefore be viewed as an indicator of order of magnitude. The approach does, however, allow for meaningful comparisons across scenarios.

Annual oil revenue accruing to OPEC more than doubles over the forecast horizon, from $160 billion in 1990 to $386 billion in 2005 (constant $1989 U.S.). In present value terms, OPEC would realize over $2 trillion from crude oil sales over the 15-year period, assuming a 10 percent rate of discount.

In many respects, this reference case scenario represents a "best-case" world for all oil market players. For OPEC members, the price-production profile described above allows for steady near-term revenue growth through output quota gains--required to subdue the fractious infighting within the Organization regarding quota allocations--and longer-term revenue gains through both price and output growth. Real price gains are sufficiently moderate to both preserve petroleum product demand growth through the 1990s and discourage rapid development of high-cost and nonconventional crude oil reserves in the non-OPEC regions.

TABLE 2.7

ANNUAL OPEC REVENUE STREAM
(billions of $1989 U.S.)

Year	Oil Revenue
1990	160
1991	173
1992	182
1993	192
1994	203
1995	215
1996	230
1997	245
1998	259
1999	278
2000	297
2001	308
2002	327
2003	345
2004	365
2005	386

SOURCE: Canadian Energy Research Institute, January 1990.

NOTE: OPEC revenue calculations are based on the production quota volumes shown in Table 2.2.

TABLE 2.8

PRESENT VALUE OF REVENUE FROM OPEC CRUDE OIL PRODUCTION
(billions of $1989 U.S.)

Discount Rate	Present Value of OPEC Revenue Stream
5%	2950
10%	2008
15%	1464

SOURCE: Canadian Energy Research Institute, January 1990.

NOTE: OPEC revenue calculations are based on the production quota volumes shown in Table 2.2.

For non-OPEC producing countries, the real price gains through the 1990s are sufficient to justify development of existing established reserves and exploration activity directed to the more promising plays and prospects. However, prices do not reach a level sufficient for development of grass-roots frontier offshore or nonconventional resources (e.g., integrated mined oil sands, two-stage coal liquefaction) until late in the 1990s. In countries where national energy strategies dictate the subsidization of domestic resource development, exploration and development activity in high-cost, hostile operating environments may not generate economic profits until well into the next century. While some industry analysts would argue that a more rapid increase in real oil prices would be of greater benefit to the non-OPEC producers, it must be borne in mind that the petroleum product consumer is more able to escape such price increases than in the past. Thus, the incremental development activity associated with higher prices could see increased oil volumes being placed onto a diminished global market, generating a replay of the oil market cycle witnessed in 1984 to 1986.

For the consumer, real crude oil price increases in the 2.0 to 3.5 percent per year range do not constitute an important cost-push element to general price inflation; indeed, these projected price gains are generally below those forecast for other energy commodities (particularly natural gas and electricity) in the industrialized countries over the forecast horizon. From a political and security of supply standpoint, the increase in petroleum product demand that would be associated with lower real price gains is clearly undesirable, at least for the industrialized nations. A lower price path, particularly a scenario with an extended price collapse into the low teens, would likely be met by increased product taxes in order to maintain product price stability. Such action would likely be more rapid, and more widespread, than that witnessed in 1986.

The exception to the above is the situation in the developing countries and their continuing struggle towards economic prosperity and parity with the industrialized world. For those developing countries which are not significant oil producers, lower crude prices would be welcomed as a reduction in hard currency requirements and a benefit to their industrial sectors.

The reference case OPEC production path contains an implicit assumption that Organization members will be able to increase productive capacity in order to service the rising call on OPEC crude, particularly in the 2000-2005 period. While there is no question that OPEC possesses the *physical reserves* to meet rising world oil demand, there is growing concern that the Organization may lack the *financial reserves* to undertake the required facilities expansion. The severe national debt problems facing many OPEC member nations--exacerbated by the financial drain of the Iran-Iraq war, growing population and social program pressures in many member countries, the continuing legacy of debt-financed expenditures undertaken in more prosperous times, and the devaluation of the U.S. dollar which lowers the purchasing power of international oil revenue--have given strength to the proposition of discretionary fiscal weakness developing within OPEC. One possible outcome arising from this situation is a modest re-integration between the multi-national oil companies and those OPEC members amenable to joint venture capital in the development of domestic resources. There is no question, however, that such a development must overcome significant hurdles in the form of religious, political and/or social opposition to foreign involvement in domestic resource development.

An alternative outcome, supported by proponents of an OPEC pricing strategy linked directly to utilization rates for OPEC productive capacity, would see a significant oil price increase accompanying the growth in demand for OPEC crude as the call on OPEC production exceeded, say, 80 percent of productive capacity (in the current reference case, this would occur in 1997). The incremental revenue accruing to OPEC would then be used to finance facilities expansion, in order to increase the production and export capacity of the Organization. Such a strategy, however, ignores the non-OPEC supply and world oil demand responses which would accompany a third upward oil price shock, and the gains being made in exploration techniques and combustion technologies which operate to increase the *speed of response* to price changes. Finally, the proven ability of non-OPEC producers to maintain production at low prices could see the aftermath of a third price shock being *greater* non-OPEC production than prior to the price gain, a *more price responsive* global end-use market, *lower* oil prices than before the shock, and *lower* OPEC revenue with a *greater* surplus capacity overhang in the market. In short, a technology-assisted compression of the 1979-1986 oil market cycle. While the temptation for OPEC to manipulate the market for near-term revenue gain will continue to exist, the cost of such an action will rise over time with the increased sophistication and flexibility of the world oil market.

Two very real uncertainties introduced into the world oil market in 1988-1989 will have significant but uncertain impacts on the oil market in the 1990s. First, the social and political upheaval in Eastern Europe and the socioeconomic reform of the Soviet Union could bring this enormous energy market more directly into the determination of global energy strategies and prices. As mentioned earlier, it is difficult to tell whether this will show up as an increase in demand for energy, as an increase in development and marketing of energy commodities, or as some likely uneven combination. Clearly, industry analysts will need to depart from their treatment of Soviet and Eastern European energy markets as "net exports" to the rest of the world, and focus in on the supply-demand characteristics and determinants in this important energy market.

The second uncertainty relates to environmental pressures and policies. This issue is briefly addressed in Chapter 3. Suffice it to say that the global political commitment to initiatives on airborne emissions will result in international protocols being signed in the next decade which will affect the way in which we produce and consume hydrocarbons. The impact on petroleum products, versus natural gas or coal, is impossible to assess at this time. Similarly, it is difficult to gauge the degree to which different nations will pursue these initiatives. However, it is clear that energy producers and consumers must become involved now in the policy-making process, in order that the most informed decisions are made in this global policy arena.

In summary, the reference price projection is dependent on continued OPEC production restraint, particularly over the next 4 to 5 years. Beyond the mid-1990s, the combination of steady petroleum product demand growth and declining non-OPEC production turns the world oil market increasingly in favour of the OPEC nations and, in particular, the reserves-rich Persian Gulf countries. The medium- to long-term benefits awaiting the Organization are expected to outweigh the near-term revenue temptation associated with rapid production or price increases, yielding a market that becomes more stable as we move through the 1990s and into the next century.

Footnotes

[1] A Ministerial Monitoring Committee comprised of delegates from Algeria, Indonesia, Iran, Iraq, Kuwait, Nigeria, Saudi Arabia, and Venezuela was formed to oversee quota violations and long-term strategies. Several of the Committee members were also mandated to undertake contacts with non-OPEC oil exporting countries to appeal for cooperation in the preservation of prices.

[2] Although the Exxon Valdez spill was the largest in the history of the U.S., it was small in comparison to the 1979 collision near Trinidad of two supertankers which spilled over 88 million gallons of oil. The Exxon Valdez spill was estimated at 11 million gallons.

[3] Output from the platform was estimated at less than 40 Mb/d, but because of the interlocking gathering and transportation system, output from 17 producing installations had to be shut in.

[4] In reality, the increases in OPEC quotas underestimated the growth in demand for OPEC oil as actual output exceeded the quota by up to 3.2 MMb/d at times.

[5] This increase will translate into an increase for oil investment which is significantly less than 10 percent, due to greater emphasis upon natural gas exploration activity (see *World Oil Market Analysis*, October/November 1989, pp. 4-6).

[6] Growth in consumption has differed significantly among OECD areas. In the first 8 months of 1989, demand in the Pacific region was up 4.5 percent, while European and North American demand was up only 1.2 percent and 0.6 percent, respectively. See International Energy Agency, *Oil Market Report*, December 1989.

[7] The additional production originates principally in U.K. and Norwegian North Sea fields. North Sea output is expected to exceed 4 MMb/d in early 1990 as repairs to the Brent Charlie platform are completed and Norway reduces its commitment to OPEC to cut production. Norway is reportedly retaliating against OPEC's appeal for cooperation from non-OPEC exporters by expanding market share.

[8] Most of the incremental capacity additions reside within the North Sea (see Section 2.2.2).

[9] This is an estimate of the cartel's maximum sustainable capacity, as provided by the United States Directorate of Intelligence, *International Energy Statistical Review* (Washington, D.C.: August 1987), p. 2.

[10] This is a reasonable assumption considering that 94 percent of non-OPEC output is economic at prices below $6.00 per barrel (1985 U.S. dollars). See *Stability Within Uncertainty: Evolution of the World Oil Market*, CERI Study No. 28, p. 82.

[11] The North Sea is proving to be a robust supply source, with daily production per producing oil well averaging over 4000 barrels. Natural pressures within the reservoir allow primary recovery techniques to extract most of the reserves. Of the 820 producing wells held by Norway and the U.K., only 20 percent require artificial lifting. This compares to 94 percent in North America and 36 percent in the Middle East. See *World Oil*, August 1989.

[12] This is a continuation of previous capacity gains in these countries. Over the past 10 years (1978-1988) they have increased annual production by 9 percent per year, on average, to a level which now exceeds total North Sea output.

[13] The strain upon western economies to relieve Eastern Bloc deficit pressures would be tremendous. Current estimates of budgetary deficits in Eastern Europe are in the area of $135 billion U.S. On the other hand, it is anticipated that assistance to the Eastern Bloc would help reduce East/West tensions, provide access to maturing markets for goods and services, and add global control and context to future environmental policies.

Chapter 3

ALTERNATIVE SCENARIOS

3.1 Introduction

The reference world oil market scenario discussed in Chapter 2 is based on a rational market approach by OPEC to future price-quantity decisions, in an environment free of market shocks. However, the volatility witnessed in the world oil market over the past 15 years suggests that these assumptions will almost certainly be violated over the next 15 years. The questions are in what manner, and in what form, future disturbances will impact on the world oil market, and the likely magnitude of market responses to these disruptions.

The CERI World Oil Market Model provides a useful framework for analyzing possible disruptions to the world oil market. This chapter examines four plausible alternative scenarios, comparing them to the reference case results discussed in Chapter 2 and providing the reader with an appreciation of the potential impact of these possible changes in the structure and operations of the world oil market. Table 3.1 provides a brief summary of the scenarios examined in this chapter.

3.2 High Non-OPEC Resource Scenario

As shown in Chapter 2, crude oil production outside of OPEC has proven to be surprisingly resilient in the face of falling real oil prices, relative to the general pessimism regarding non-OPEC supply potential that lay behind the high oil price projections formulated in the late 1970s. Not only have the non-OPEC producers shown the ability to maintain production levels in the presence of low oil prices (as evidenced in 1986 and discussed in Chapter 3 of *Stability Within Uncertainty*), but technological advances have served to lower the exploration and development costs of new field development in increasingly hostile operating environments. This has allowed for the expansion of high cost offshore facilities (e.g., North Sea and Brazil) and the development of new producing regions (e.g., Colombia, North and South Yemen) during the period of declining prices and price uncertainty which characterized the 1980s.

TABLE 3.1

ALTERNATIVE MARKET SCENARIOS

Scenario Title	Scenario Description
High Non-OPEC Resources	Higher ultimate potential reserves estimate (5 percent probability level) assumed for all non-OPEC, non-CPE producing nations.
OPEC Price-Quantity Strategies	OPEC strategies directed to more aggressive price gains or more aggressive volume gains over the first half of the 1990s.
Environmental Initiatives	Environmental excise tax of 10 percent levied on end-use prices for gasoline and heavy fuel oil in the OECD countries.
Centrally Planned Economies Scenario	Net crude oil exports from China decline to zero by 1995. Crude oil demand growth in the Soviet Union and Eastern Europe is accelerated on the basis of higher economic growth, beginning in 1993. Crude oil production increases above the reference case, beginning in the late 1990s.

SOURCE: Canadian Energy Research Institute.

Estimates of recoverable world oil resources vary widely, depending on the assessor.[1] Table 3.2 provides a range of these estimates at three probabilities of occurrence for the non-OPEC producers, together with reserves estimates and reserves-to-production ratios for each country as of 1988. These estimates suggest that anywhere from 245 billion to 490 billion barrels of crude oil reserves exist in the non-OPEC, non-CPE regions. Given that the developing countries have been explored far less intensively than North America and the North Sea, it is not unreasonable to suppose that the higher ultimate potential figures could, in fact, be realized. As important, if the higher ultimate potential figures are closer to the true extent of the non-OPEC crude oil reserves, then a given volume of drilling activity would be expected to generate a higher volume of reserves additions and future oil production.

The structure of the CERI World Oil Market Model allows for the examination of the upside potential for crude oil resources in the non-OPEC producing countries. Referring to the model description in Appendix A, a higher value for undiscovered resources in a given country or region will push up projected finding rates in that region, yielding a higher time path of future discoveries from a given level of drilling activity. In this scenario, the ultimate potential estimate for each non-OPEC country is switched to the 5 percent probability level from the modal estimate (which is used in the reference case projections and all other alternative scenarios, unless otherwise specified). All other reference case assumptions, including the projected level of OPEC production, are unchanged.

Figures 3.1 and 3.2 summarize the essential features of the high non-OPEC resource scenario, comparing them with the reference case projections. As shown in Figure 3.1, if assumptions regarding OPEC production levels are held constant, prices are significantly lower in the high non-OPEC resource case than in the reference case. The oil price remains in the $20 to $22 (U.S.) per barrel range throughout the 1990s, reaching $22.00 per barrel by the year 2000. This is roughly 15 percent below the reference case price of $26.10 per barrel in 2000. Prices rise steadily into the next century, reaching $23.55 per barrel in 2005, on the strength of rising demand growth. Total world crude oil consumption in 2005 is projected to reach just under 85 MMb/d, over 6.0 MMb/d above the projected reference case demand level.

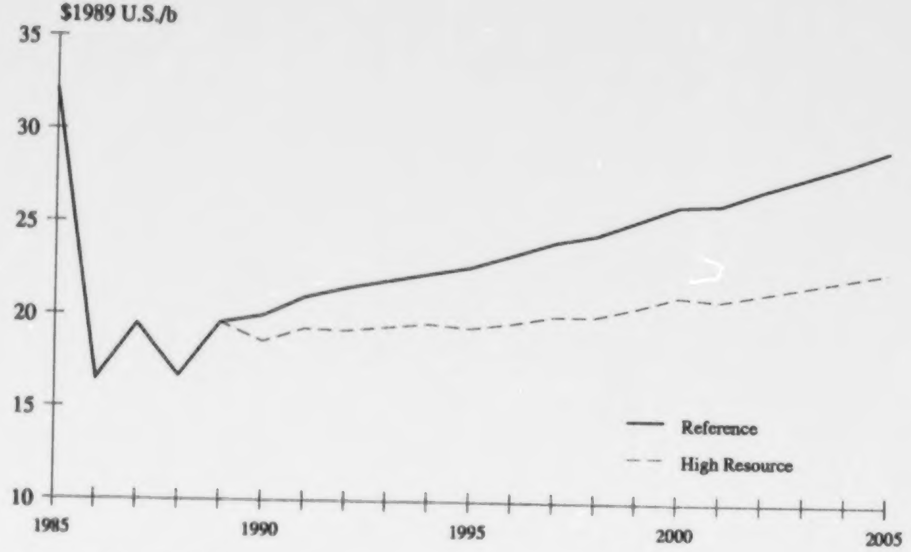
TABLE 3.2

ULTIMATE POTENTIAL CONVENTIONAL CRUDE OIL RESOURCES IN THE NON-OPEC COUNTRIES
(billions of barrels)

	Proven Reserves (as of 1988)	Reserves to Production Ratio (as of 1988)	Ultimate Potential Reserves		
			(95%)	(Mode)	(5%)
Angola	4.2	20.0	7.1	11.5	14.2
Argentina	2.2	14.7	7.5	8.5	12.2
Australia	2.5	16.7	7.5	9.5	14.5
Brazil	2.5	10.6	7.4	9.0	12.6
Canada	6.8	11.2	22.2	24.6	26.5
Colombia	4.0	15.6	7.9	9.5	13.5
Egypt	4.7	20.0	9.0	11.0	14.2
India	4.8	19.2	8.5	10.5	14.5
Malaysia	5.0	16.7	10.0	11.5	19.8
Mexico	54.1	55.6	83.5	108.0	227.0
North Sea	15.6	17.2	30.5	38.3	55.5
Other Middle East	12.2	21.7	19.8	28.0	28.0
United States	27.3	8.0	17.9	19.7	21.9
Western Europe	2.4	13.3	6.0	7.0	14.5
Total	148.3		244.8	306.6	488.9

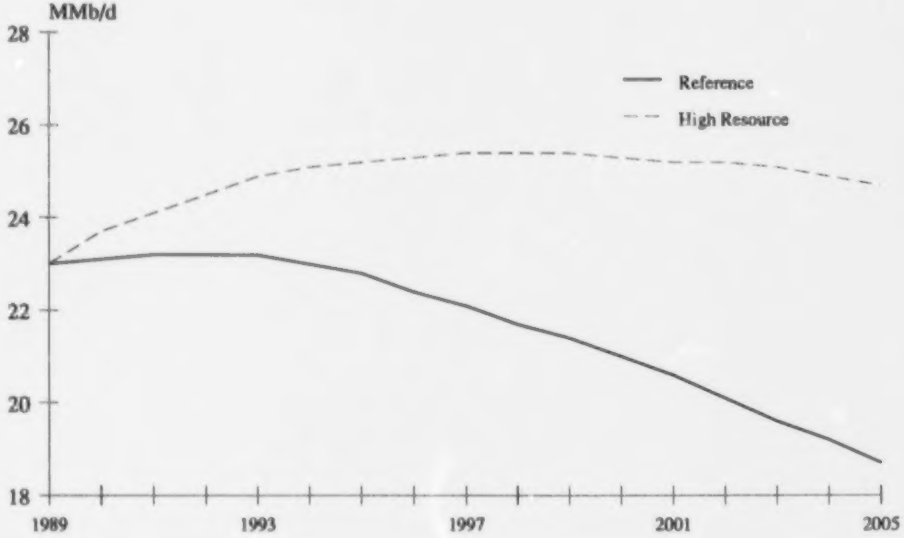
SOURCE: *World Oil*, various issues; *Geological Survey Circular 860*, "Estimates of Undiscovered Recoverable Conventional Sources of Oil and Gas in the United States (1981)"; United States Department of Energy, Energy Information Administration, *"Foreign Energy Supply Assessment Series"*; and Masters, Root and Dietzman, *Distribution and Quantitative Assessment of World Crude Oil Reserves.*

Figure 3.1
High Non-OPEC Resource Scenario
World Oil Prices



SOURCE: CERI, January 1990.

Figure 3.2
High Non-OPEC Resource Scenario
Non-OPEC Production



SOURCE: CERI, January 1990.

Lower crude oil prices and greater demand growth relative to the reference case are the product of greater non-OPEC crude oil production throughout the forecast horizon. Lower levels of drilling activity in the non-OPEC regions, associated with lower oil prices relative to the reference case, are more than offset by higher finding rates associated with the expanded reserves base. Non-OPEC production peaks later (1998-1999 versus 1992-1993) and at a higher level (25.4 MMb/d versus 23.2 MMb/d) than under the reference case. The higher returns to drilling activity also mitigate the decline in non-OPEC production relative to the reference case. By the year 2005, non-OPEC crude oil output falls only 500 Mb/d from its peak of 25.4 MMb/d in 1998-1999. Under the reference case, production levels are projected to decline by 4.5 MMb/d from the peak of 23.2 MMb/d, falling to 18.7 MMb/d by 2005.

The impact of the high non-OPEC resource scenario on OPEC revenue is significant. Although OPEC production gains are assumed to match those in the reference case, the weaker market prices yield a decline in the present value of revenues accruing to OPEC of over $280 billion ($1988 U.S.) relative to the reference case. This result is roughly consistent with OPEC choosing to maintain a constant real $20 (U.S.) per barrel crude price through the projection period.

Under a variation of the high non-OPEC resource scenario in which OPEC would restrain production to defend the reference case price path, the revenue results are essentially the same. Such a scenario would see OPEC production increasing by only 3.5 MMb/d over the 1990s, to 25.3 MMb/d in 2000. Non-OPEC production gains would be even greater, peaking at 27.0 MMb/d in 2001-2002 on the strength of higher prices and the high resources assumption. OPEC would not regain a 50 percent share of the non-CPE oil market until 2003. The present value of the revenue stream accruing to OPEC under this scenario would total just over $1.75 trillion ($1988 U.S.) versus $1.72 trillion in the high non-OPEC resource scenario and just over $2.0 trillion in the reference case.

In our view, the high resource scenario provides a very legitimate alternative to the reference case scenario, in terms of the most-likely future path for crude oil prices. Continued advances in seismic and drilling technology, which lower the hurdle price for new field development, would tend to reinforce this projection of continued non-OPEC production gains. This applies similarly to the advances being made in nonconventional oil liquids technologies and enhanced oil recovery techniques, the latter aimed at accessing the roughly 50 to 60 percent of remaining oil-in-place in a pool after exhaustion of primary and secondary (largely water flood) drive.

The success of non-OPEC producers in maintaining and expanding non-OPEC production capabilities will tend to both depress oil market prices and postpone the development of a market environment in which OPEC can successfully manoeuvre for accelerated real price gains. Such a scenario is clearly of benefit to consumers of refined petroleum products, although this must be tempered by concern over the attendant increase in reliance on crude oil supplies and increased exposure to future oil market developments.

3.3 OPEC Price-Quantity Strategies

The price-quantity strategy ascribed to OPEC in the reference case--gradual and controlled increases in both real crude oil price and production volumes through the 1990s--is only one of many possible market strategies available to OPEC, depending on the degree of internal unity and proactive cartel behaviour which one ascribes to the Organization. One particular strategy (termed the Market Manipulation Scenario) in which OPEC would systematically increase production volumes and lower oil prices in order to restore the industrialized world's dependence on OPEC crude, and then exploit that dependence with a series of dramatic oil price increases, repeating the cycle as market conditions and market response warranted, was analyzed in detail in *Stability Within Uncertainty*. There it was shown that this "roller-coaster" scenario--even if it were possible to implement--was clearly inferior from a revenue standpoint to a strategy of gradual price-quantity gains.

The results of that analysis led to the conclusion that, given the lack of non-OPEC production response to even a 2- to 3-year period of low oil prices, the positive non-OPEC exploration and development response to periods of high oil prices, and the lag in demand response to oil price changes, not only was such a strategy administratively difficult from the standpoint of OPEC management of production volumes, but also counterproductive from a market share standpoint. The observation that incremental non-OPEC production facilities established in response to high oil prices would not be shut-in during periods of low oil prices resulted in OPEC's market share shrinking with each completed phase of the "roller-coaster" cycle.[2]

This continues to be the case in the current set of world oil market projections. If the goal of OPEC is to maximize its long-term crude oil revenues, then such a dramatic market manipulation strategy fares very badly in comparison to the reference case scenario of Chapter 2.

However, there are many other price-quantity combinations open to OPEC. In discussing alternative strategies, we have chosen to focus on the 1990-1996 period. This is the period in which the oil market continues to be dominated by significant surplus productive capacity and, hence, a certain degree of price fragility. After this period, medium-term excess capacity in the market is not only at or below 11 percent of non-CPE world production (20 percent of OPEC production), but is located exclusively in Venezuela and the Persian Gulf OPEC nations. Such a market environment would presumably be much more amenable to OPEC control, while the Organization itself would presumably be a much more unified and cohesive market player. The critical question is, what is the "best" way to arrive at this market situation from the current environment.

To shed some light on the implications of various OPEC market strategies, we have selected two intuitively appealing scenarios to examine. The first scenario (termed Near-Term Production Gains) would see OPEC adjusting production to maintain a fixed crude oil price (assumed to be $18 (U.S.) per barrel in constant 1990 dollars) through 1996, and then increasing prices in equal annual increments thereafter to merge with the reference case price path in 2001. The second scenario (termed Near-Term Price Gains) would see OPEC maintaining its current production level of 22.0 MMb/d through 1996 and then increasing production volumes in equal annual increments until the reference case OPEC production profile is reattained in 2001.

These two options--near-term price gains versus near-term production gains--roughly correspond to the two camps within OPEC. Those countries currently producing near capacity and/or possessing relatively small crude oil reserves argue in favour of near-term price gains, as they are in a relatively poor position to benefit from more rapid market growth. Those countries which possess significant excess productive capacity and/or relatively large crude oil reserves argue in favour of near-term production gains based on low, stable oil prices, market growth and stable (or gradually declining) non-OPEC production.

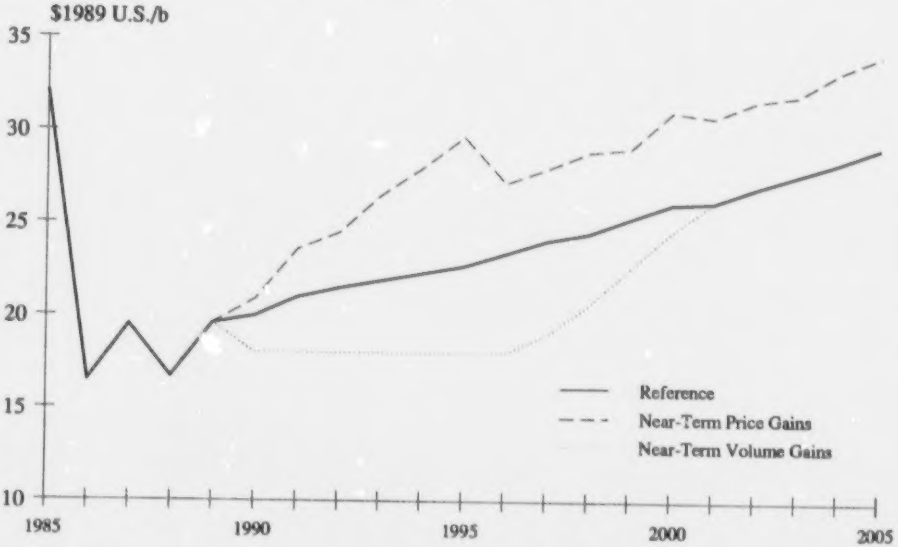
The strategy adopted by OPEC since late 1988 is in keeping with the near-term production gain scenario. Extension of this scenario over the first half of the 1990s would yield OPEC production at just under 34 MMb/d in 1995, some 8.0 MMb/d above the corresponding reference case output level. The increase in real oil prices over the second half of the decade--from $18 (U.S.) per barrel in 1996 to $26.65 per barrel by the year 2000--would both curb demand growth and stimulate non-OPEC production, resulting in a corresponding decline in the growth of OPEC production. In fact, the call on OPEC crude under this scenario is projected to decline in the 2000-2005 period from a peak of 35.2 MMb/d, stabilizing around 34.0 MMb/d. Non-OPEC production shows a lower peak level relative to the reference case (23.0 MMb/d vs. 23.2 MMb/d, respectively) and declines somewhat more quickly through the 1990s to roughly 1.0 MMb/d below the reference case level in 2000. However, the upward movement in real prices over the last half of the 1990s serves to stimulate exploration and development activity, resulting in a more gradual decline in non-OPEC production in the 2000-2005 period. Non-OPEC production in 2005 is virtually identical to that in the reference case.

Under the near-term price gain strategy, OPEC production constrained to 22 MMb/d over the 1990-1995 period results in a rapid escalation of oil prices, relative to the reference case (see Figure 3.3). Oil prices reach just under $30.00 per barrel in 1995 compared to $22.70 under the reference case. Subsequent increases in OPEC production over the 1995-2000 period force oil prices down to the $27 to $28 per barrel level, recovering to $31 to $34 per barrel over the 2000-2005 period. Non-OPEC production volumes are maintained near the 23 MMb/d level throughout the 1990s in response to the higher oil price track and are some 1.0 MMb/d above the reference case level in 2000.

Total crude oil demand in 2005 is roughly equivalent under the near-term price gain and production gain strategies at 75.5 MMb/d, over 3.0 MMb/d below the reference case level of 78.8 MMb/d (see Figure 3.4). This is due to the increase in oil prices under both alternative OPEC price-production strategies, which affect demand in a similar fashion although the temporal pattern of the price gains is different. It is important to note, however, that under the near-term price gain strategy crude oil demand is rising through the 1995-2005 period, while under the near-term production gain strategy oil demand is actually falling from a peak of 78.0 MMb/d in the late 1990s. Thus, while the two strategies yield a forecast horizon oil market of roughly

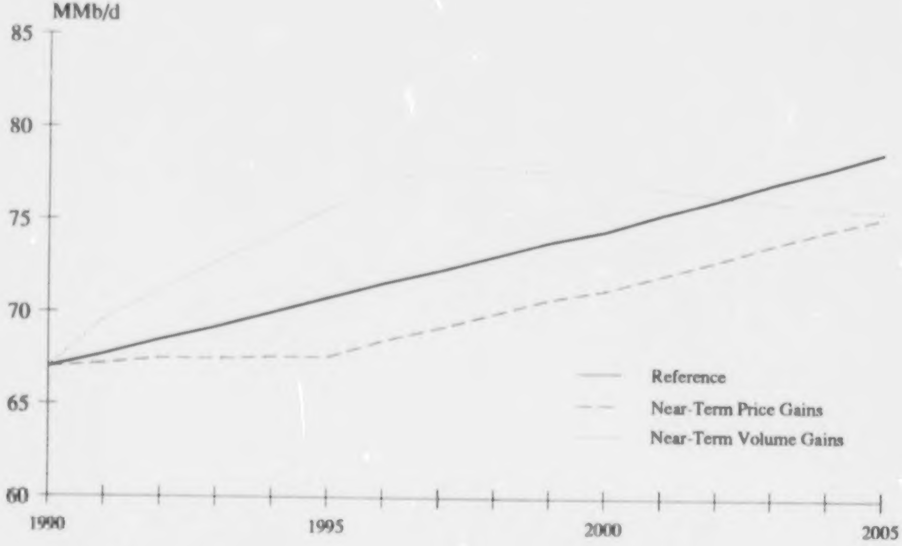
Figure 3.3

Alternative OPEC Strategies
World Oil Prices



SOURCE: CERI, January 1990.

Figure 3.4
Alternative OPEC Strategies
Market Clearing Volumes



SOURCE: CERI, January 1990.

the same size, the market is growing under the first strategy and declining under the latter.

It is also interesting to note that the present value of the revenue stream to OPEC is virtually identical under the reference case and the two alternative price-production strategies, at roughly $2.0 trillion (assuming a 10 percent discount rate; see Table 3.3).

TABLE 3.3

COMPARISON OF PRESENT VALUE OF
OPEC CRUDE OIL PRODUCTION
1990-2005
(billions of $1988 U.S.)

Discount Rate	Reference Case	Near-Term Price Gains	Near-Term Production Gains
5%	2950	2960	2946
10%	2008	2023	1986
15%	1464	1480	1436

SOURCE: Canadian Energy Research Institute.

Therefore, the choice of strategy really becomes a question of what type of market OPEC desires in the long term. Under a near-term price gain strategy, OPEC would create a market that is growing as we enter the next decade. Under the near-term production gain strategy, it would see a market in decline, albeit from a larger size in the 1990s. Under the reference case price-production strategy, the Organization could see a market that is larger and gradually expanding. Again, the combination of gradual price-production gains through the next decade would appear to be a dominant strategy in terms of market share and market size, even if it is revenue neutral in comparison to the alternative price-production strategies.

3.4 Environmental Initiatives Scenario[3]

The scenarios discussed above and in the reference case of Chapter 2 are based on the assumption of static fiscal regimes and reasonable growth rates for the various economies and regions being assessed. By holding these variables constant across scenarios, it is easier to isolate the impact which particular market shocks will have on the evolution of world oil demand, supply and prices.

As discussed in Chapter 2, there are at least two key uncertainties--environmental legislation and developments in the Soviet bloc--which could significantly alter the assumptions underlying the scenarios examined to this point. This section examines the potential impact on the world oil market resulting from fiscal initiatives directed towards the reduction of carbon dioxide (CO_2), nitrogen oxide (NO_x) and sulphur dioxide (SO_2) emissions into the atmosphere.

3.4.1 Atmospheric Emissions

Recent public opinion polls suggest that environmental issues are rivalling unemployment, inflation and government deficits as a principal source of social concern.[4] This concern, and much of the associated response by governments around the world, is focussed to a large extent on atmospheric pollution. In this context, a number of clearly distinguishable sources of concern have been identified, including acid rain, ground level ozone (urban smog) and global warming--the "greenhouse effect." Each of these issues is associated with emissions of SO_2, NO_x, VOCs (volatile organic compounds) and CO_2.

Acid rain and ground level ozone can be loosely categorized as local or regional issues with localized, technological solutions. While international protocols have been signed under the United Nations Economic Commission for Europe (UNECE) Convention on Long Range Transboundary Air Pollution (LRTAP) regarding reductions in SO_2 emission levels (1985) and NO_x emission levels (1988), the actions to be taken are expected to be related to localized technological retrofits to combustion facilities and limited use of hydrocarbon substitutes (e.g., alcohol fuels) in transportation applications.

From the standpoint of refined petroleum product consumption, the greater uncertainty appears to lie with potential environmental initiatives related to $\underline{CO_2\text{ emissions and global warming}}$. At this time, the magnitude and timing of possible changes in global climate conditions which may occur as a result of increased concentration of greenhouse gases in the atmosphere is subject to considerable uncertainty within the scientific community. However, there is little debate that the concentration of greenhouse gases has increased over the last century; that atmospheric CO_2 concentrations--which contribute to roughly 50 percent of the increased greenhouse gas concentration--have increased some 10 percent over the last 30 years; and that manmade emissions of CO_2 have more than doubled over the same period.

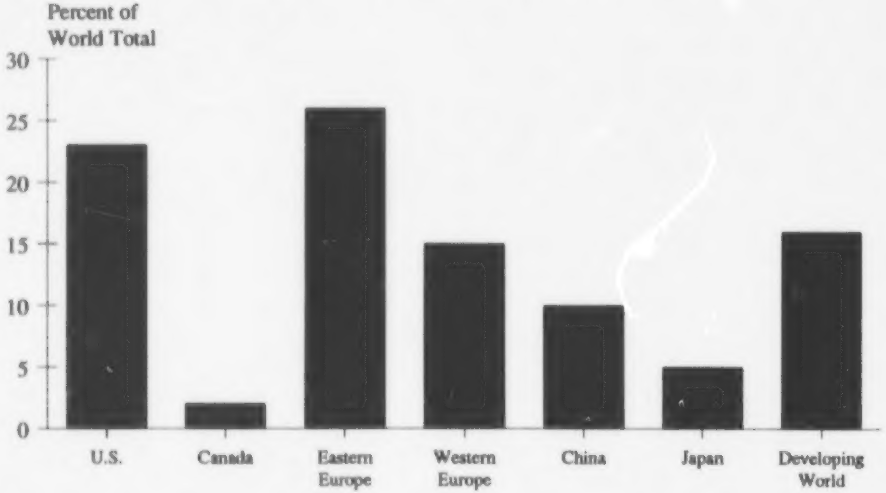
3.4.2 Dimensions of the CO_2 Issue

Reduction in greenhouse gas emissions--and particularly the control of CO_2 emissions--is generally viewed as a global problem requiring global solutions. The following points are worthy of particular note:

- Global emissions of CO_2 are widely dispersed over different regions of the developing and developed world (see Figure 3.5).
- **Unlike SO_2 and NO_x emissions, there is no proven technology currently available for reducing CO_2 emissions.** Rather, in the absence of reduced growth in energy demand, fuel switching and improved energy efficiency are the only known means of curbing global CO_2 emissions. Efforts to utilize CO_2--such as injection technologies for enhanced oil recovery--have significant potential, although the question of containment requires further investigation.
- The scope for achieving energy efficiency gains varies widely across countries and regions. Many LDC countries lag decades behind the industrialized countries in terms of overall efficiency gains.
- Worldwide emissions of CO_2 more than tripled between 1950 and 1980, and the pattern of global contribution has been changing in parallel with the growth of industrialization. North America and Western Europe together accounted for 43 percent of total CO_2 emissions in 1980, versus 68 percent in 1950. In contrast, the portion attributable to the People's Republic of China and the developing countries in Africa, Latin America and Southern Asia grew from 7 percent to over 20 percent of the world total (see Figure 3.6).[5]

While giving due consideration to the uncertainty surrounding the timing and magnitude of the greenhouse effect, the possible social and economic implications are staggering. At a two-stage workshop in Villach (Austria) and Bellagio (Italy),[6] a group of over 400 scientists examined how climate change resulting from increasing concentrations of greenhouse gases could affect the environment and society during the coming century. Under the "upper bound" scenario, which assumes that no concerted effort is made to reduce emissions of greenhouse gases, global surface temperatures were predicted to increase by 0.8 degrees centigrade per decade until the middle of the next century. The most extreme temperature increases would likely occur in the higher latitude of the Northern

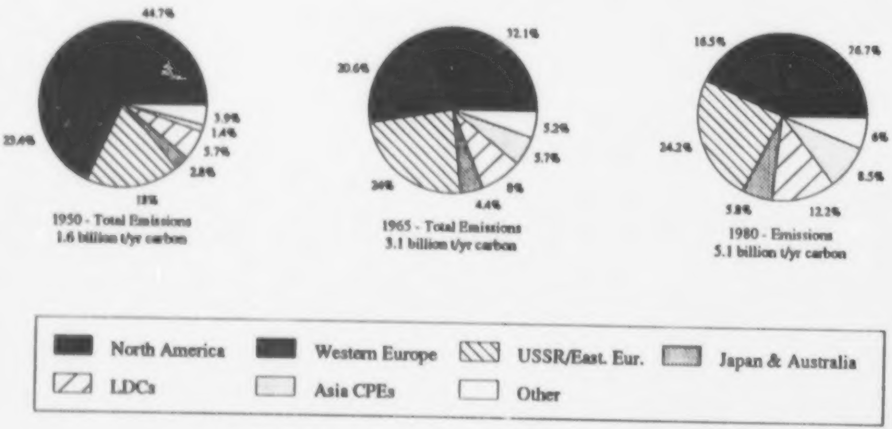
Figure 3.5
Industrial $C0_2$ Emissions - 1985
by Country/Region



SOURCES: World Resources Institute and
International Institute for Environment
& Development, World Resources 1988-89.

Figure 3.6

CO_2 Around the World



1950 - Total Emissions
1.6 billion t/yr carbon

1965 - Total Emissions
3.1 billion t/yr carbon

1980 - Emissions
5.1 billion t/yr carbon

SOURCE: Electric Power Research Institute,
EPRI Journal, June 1988.

Hemisphere during the winter months, when the increase in temperature could be more than twice the global average.

As a result of these temperature changes, precipitation patterns could be changed dramatically, the severity and frequency of extreme weather disturbances could increase, and sea levels could rise by as much as 1.5 metres--creating havoc in coastal areas.

While the political and social implications of these possible outcomes have yet to be determined, the potential economic impact could be enormous. This has led many of the political and scientific leaders of the industrialized countries to call for significant, near-term actions ranging from domestic fiscal initiatives (e.g., fuel taxes, carbon taxes, tradeable pollution credits) to international initiatives such as the reforestation of the rain forests in Central and South America.

The major wild card in this movement to address greenhouse gas emissions is the actions of developing countries. Already saddled with staggering international debt, and dependent on inexpensive energy to fuel their continued pursuit of economic development, these countries may quite simply not be in a position to finance the energy efficiency gains and clean combustion technologies required to address a reduction in atmospheric emissions. This is particularly worrisome as the developing countries are projected to have the highest growth in energy demand over the next 15 years, and the majority of this growth is expected to be in the form of coal and fuel oil consumption. While sympathetic to the cause and implications of the greenhouse effect, leaders of the developing countries must take certain exception to being asked to contribute now to the correction of a potential environmental crisis which was manufactured through the industrialization of the developed countries.

3.4.3 Environmental Scenarios

Fully addressing the question of reduction in atmospheric emissions on a global basis clearly requires a comprehensive energy use model, flexible enough to examine a number of fiscal and emission guideline options. While the CERI World Oil Market Model falls short of this objective, it is useful in examining the potential impact of the imposition of end-use taxes on petroleum product demand and, hence, on world oil prices.[7] In developing this scenario, we made a number of simplifying assumptions.

1. Given the discussion in Section 3.4.2, it was assumed that no action would be taken in the developing countries to curb energy demand growth.

2. In the industrialized countries, atmospheric emissions can be largely credited to transportation and industrial activity (e.g., combustion of hydrocarbons for process heat and electricity generation).[8] Therefore, it was assumed that fiscal initiatives would be directed to the gasoline and heavy fuel oil product categories within the World Oil Market Model.

3. For various political and economic reasons, it was assumed that the actions of the industrialized countries would be phased into effect. Therefore, fiscal initiatives are assumed to be put in place in North America in 1990, Australasia (including Japan) in 1992, and Western Europe in 1995.

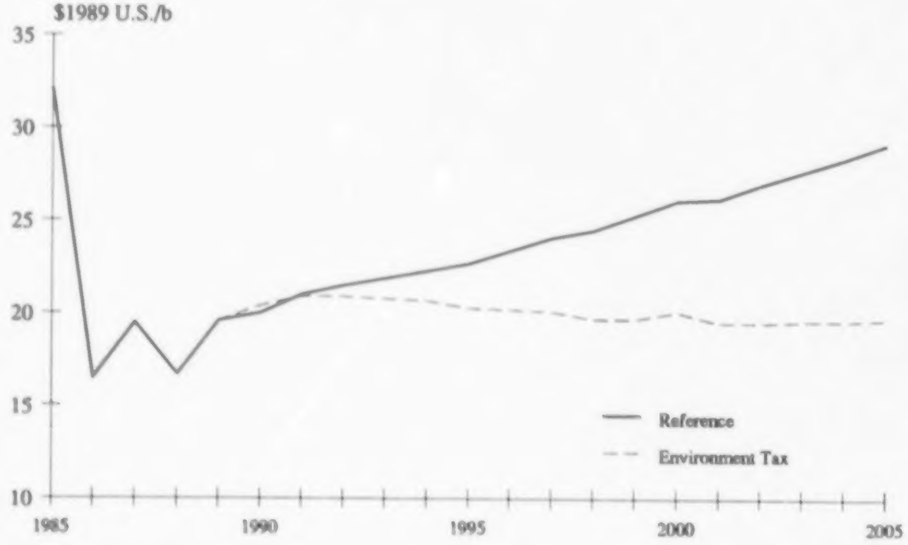
The scenario involves the application of a 10 percent product tax on gasoline (including diesel fuel) and heavy fuel oil consumption, levied at the burner-tip. For simplicity, all assumptions regarding economic growth rates in the various demand regions and the future path of OPEC production are unchanged from the reference case.

Figure 3.7 shows the impact on world oil prices of the phased-in product tax. After rising to $21 per barrel in 1992, prices vacillate between $19.50 and $20.50 per barrel throughout the forecast period. This is due to the sequential dampening impact on world oil demand arising from the imposition of the product taxes in the various industrialized regions.

Figures 3.8 and 3.9 illustrate the impact on product demand in the industrialized countries relative to the reference case. Of particular note is the depressing effect of the product taxes on product demand, which declines from 18.2 MMb/d in 1990 to under 13 MMb/d in 2005 for gasoline, diesel and heavy fuel oil combined. This compares to a 2.3 MMb/d increase in product demand across these product categories under the reference case, yielding the potential for an almost 8 MMb/d difference in combined gasoline, diesel and heavy fuel oil consumption between the two scenarios in 2005.[9]

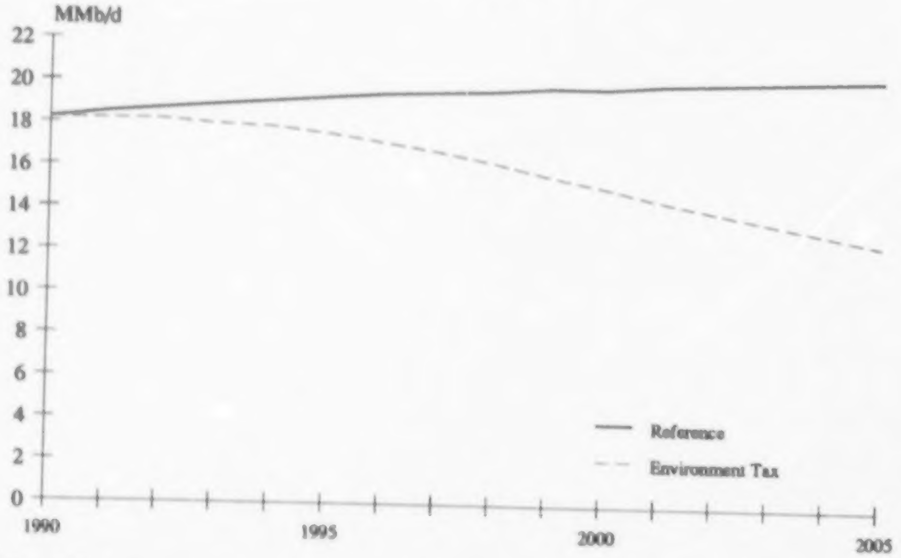
As expected, the 10 percent surcharge on product prices is projected to have a significant effect on product consumption. However, two competing forces act to partially offset this result. First, the lower crude oil price track relative to the reference case boosts demand growth for middle distillates and other petroleum products in the

Figure 3.7
Environment Tax Scenario
World Oil Prices



SOURCE: CERI, January 1990.

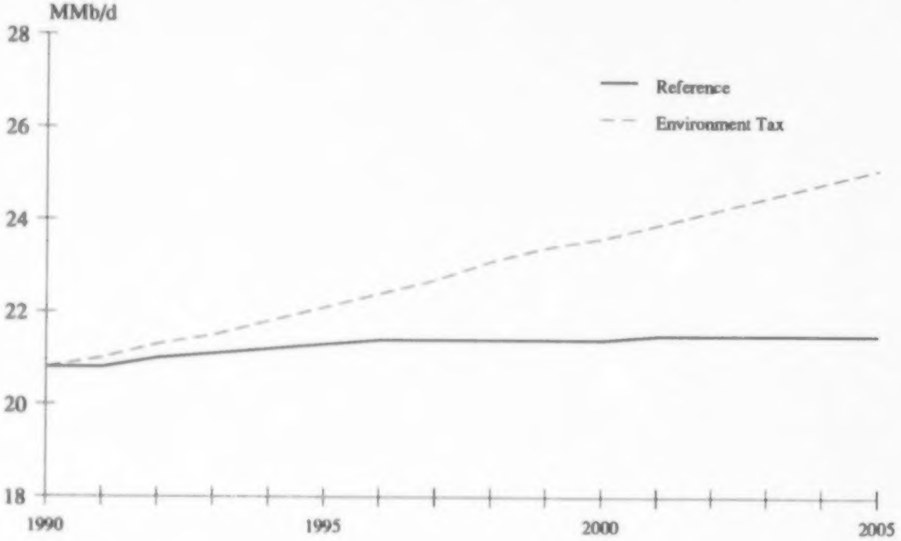
Figure 3.8
Gasoline and Heavy Fuel Oil Demand
Industrialized Countries



SOURCE: CERI, January 1990.

Figure 3.9

Middle Distillates and Other Product
Demand - Industrialized Countries



SOURCE: CERI, January 1990.

industrialized countries, rising from 20.8 MMb/d in 1990 to over 25 MMb/d in 2005, versus a reference case level of 21.5 in 2005. Thus, roughly 3.5 MMb/d of the 8 MMb/d consumption decline attained through the product taxes is lost to higher demand growth in the other product categories in the industrialized countries.

Second, the lower crude oil price track also stimulates demand growth in the developing countries (see Figure 3.10). Without the influence of product taxes, the developing countries (including OPEC) take full advantage of the lower crude oil and product prices, relative to the reference case. Combined product demand increases from just under 14 MMb/d in 1990 to over 22 MMb/d in 2005, compared to a reference case demand level of 19.3 MMb/d in 2005. Thus, by the end of the forecast period an additional 3 MMb/d of the 8 MMb/d product consumption decline achieved through product taxes in the industrialized countries is offset by LDC demand growth.

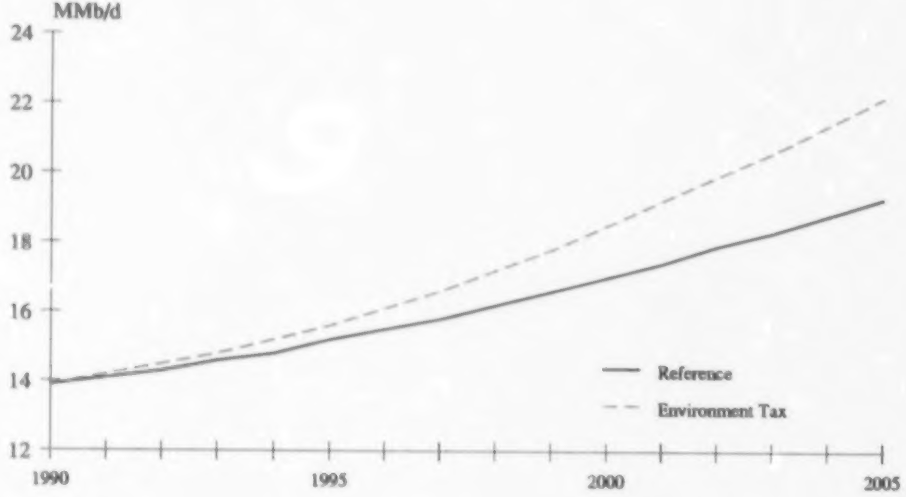
In summary, the net impact on world oil demand of the 10 percent phased-in surcharge on end-use prices for transportation fuels and heavy fuel oil in the industrialized countries is roughly 1.5-2.0 MMb/d per year by the end of the forecast horizon. Factoring in higher LDC economic growth as a result of the relative energy price advantage accruing to these countries would essentially eliminate the impact of the product tax on world oil volumes.[10]

The important conclusion to draw from this scenario is that national and regional initiatives to reduce oil product consumption, for environmental or other reasons, will not be successful unless all countries are involved in the exercise. Gains made in one jurisdiction in reducing petroleum product demand will show up, through the oil market, as price-based incentives to increase petroleum product consumption in other regions. In the absence of global cooperation, such a piecemeal approach to the reduction in hydrocarbon consumption will have little impact beyond generating considerable revenue to those governments imposing the tax and transferring a cost of production and terms of trade advantage to those who choose not to impose the tax.

3.5 Centrally Planned Economies Scenario

The second key uncertainty over the next 15 years which we have selected to address in this study is the potential impact of perestroika and glasnost on Soviet and Eastern European economic development, energy demand and supply, and ultimately the net crude oil

Figure 3.10
Refined Petroleum Product Demand
Developing Countries



SOURCE: CERI, January 1990.
NOTE: Excludes centrally planned economies.

export/import position of the centrally planned economies (CPEs) in the world oil market.

The reference case scenario discussed in Chapter 2 incorporates a supply-demand profile for the CPEs which projects gradually increasing oil production (16.2 MMb/d in 1990 to 17.5 MMb/d in 2005) outpaced by demand growth, resulting in net exports from the CPEs declining to zero by 1999 and remaining at that level through 2005 (see Table 3.4). As discussed in Chapter 2, the potential for deviation from this supply-demand profile is not only significant, but directionally uncertain. A more rapid decline in net CPE oil exports could result from a number of factors. First, support from Western Europe and North America for the pro-democracy movements in Eastern Europe through, for example, the provision of financial and human capital to support industrialization within the Eastern European countries, would lead to much stronger energy (and refined petroleum product) demand growth than envisaged under the reference case. This would be accentuated by the deployment of older production processes and technologies, which tend to be more energy intensive and less energy efficient.

Second, a withdrawal from the current policy of off-oil conversion to natural gas within the Soviet bloc--orchestrated out of Moscow in order to release domestic crude oil for export to increase foreign currency reserves--could result from the loosening of central party control over the Eastern bloc countries. This would tend to accelerate crude oil demand growth over the forecast period, relative to the reference case. Numerous other factors, such as relaxed import controls on transportation vehicles, could also contribute to more rapid crude oil demand growth within Eastern Europe and the Soviet Union.

At the other end of the spectrum, a number of factors could operate to increase the net supply of crude oil placed on the world oil market by the CPEs. First and foremost would be a movement by private sector oil companies to become involved in oil exploration and development in the Soviet Union, either through joint venture or direct equity involvement. The resulting influx of financial capital and, more importantly, advanced seismic, drilling and production technologies, could result in more rapid development of the hydrocarbon reserves potential in the Soviet Union. Clearly, such involvement by western companies on any significant scale would require assurances that changes within the Soviet Union--particularly regarding private sector development and private sector returns from resource exploitation--

TABLE 3.4

CRUDE OIL SUPPLY-DEMAND PROFILE CENTRALLY PLANNED ECONOMIES REFERENCE CASE

Year	Crude Oil Supply (MMb/d)	Crude Oil Demand (MMb/d)	Net Exports (MMb/d)
1990	16.2	14.0	2.2
1991	16.2	14.2	2.0
1992	16.2	14.4	1.8
1993	16.2	14.6	1.6
1994	16.2	14.8	1.4
1995	16.2	15.0	1.2
1996	16.3	15.3	1.0
1997	16.3	15.5	0.8
1998	16.4	15.8	0.6
1999	16.3	16.0	0.4
2000	16.2	16.2	0.0
2001	16.5	16.5	0.0
2002	16.7	16.7	0.0
2003	17.0	17.0	0.0
2004	17.2	17.2	0.0
2005	17.5	17.5	0.0

SOURCE: Canadian Energy Research Institute, January 1990.

were both ongoing and unlikely to be reversed. Convincing private companies to put up capital for crude oil exploration and development in the Soviet Union could well be a lengthy and arduous task, leading many analysts to suggest that the demand-side influence of perestroika and glasnost may be the dominating influence on CPE energy markets in the 1990s.

The scenario presented below attempts to incorporate these uncertainties through a phased demand-supply response within the CPEs. The positive impacts of economic change within the Eastern European countries and the Soviet Union are assumed to show up in accelerated economic growth (and energy demand growth) beginning in the 1992-1993 period, potentially accentuated by support from the industrialized countries. Economic growth rates are assumed to increase by 0.5-1.5 percentage points annually relative to the reference case. On the supply side of the equation, it appears reasonable to suggest that private sector joint ventures in the Soviet Union would require somewhat more time to show up in any significant volume. Therefore, we assume that incremental exploration and development activity (relative to the reference case) is not forthcoming until 1994-1995, and is not reflected in production volumes until 1997. After that point, however, crude oil production is seen to increase fairly rapidly, exceeding the reference case production level by roughly 20 percent in 2005. This temporal pattern of supply developments is consistent with expectations of declining non-OPEC production and rising real crude oil prices through the latter 1990s which would encourage private oil companies to pursue the crude oil potential of the Soviet Union and, presumably, aid in lowering the resistance to the perceived political and economic risks associated with such activity.

The other key member of the CPE category--the People's Republic of China--is assumed to be unaffected by developments in the Eastern bloc countries. The reference case demand-supply profile is assumed to continue to apply, with growth in refined petroleum product demand outstripping the growth in domestic oil production, resulting in a decline in crude oil exports to zero by 1993. From that point on, China is assumed to have a neutral impact on world oil market development. All other scenario assumptions, including the production profile for OPEC, are unchanged from the reference case.

Table 3.5 provides the demand-supply profile resulting from this scenario. Demand growth in the CPEs is increased through acceleration of economic growth rates relative to the reference case.

TABLE 3.5

CRUDE OIL SUPPLY-DEMAND PROFILE CENTRALLY PLANNED ECONOMIES ALTERNATIVE SCENARIO

Year	Crude Oil Supply (MMb/d)	Crude Oil Demand (MMb/d)	Change in Net Exports from Reference Case (MMb/d)
1990	16.2	14.0	0.0
1991	16.2	14.2	0.0
1992	16.2	14.4	0.0
1993	16.2	14.6	0.0
1994	16.2	14.9	-0.1
1995	16.2	15.1	-0.1
1996	16.3	15.5	-0.2
1997	16.6	15.8	0.0
1998	16.9	16.1	0.2
1999	17.1	16.3	0.4
2000	17.3	16.7	0.6
2001	17.8	17.0	0.8
2002	18.4	17.4	1.0
2003	19.0	17.8	1.2
2004	19.6	18.1	1.5
2005	20.2	18.5	1.7

SOURCE: Canadian Energy Research Institute, January 1990.

Economic growth is increased by 0.5 percent over the 1993-1995 period, 1.0 percent over the 1996-2000 period, and 1.5 percent during the 2001-2005 period, relative to the reference case growth rates. This yields annual economic growth rates in the first decade of the next century at 5.0 percent per year, an optimistic figure but certainly attainable with sufficient external aid (financial and technical) applied to the human and natural resources of Eastern Europe and the Soviet Union.

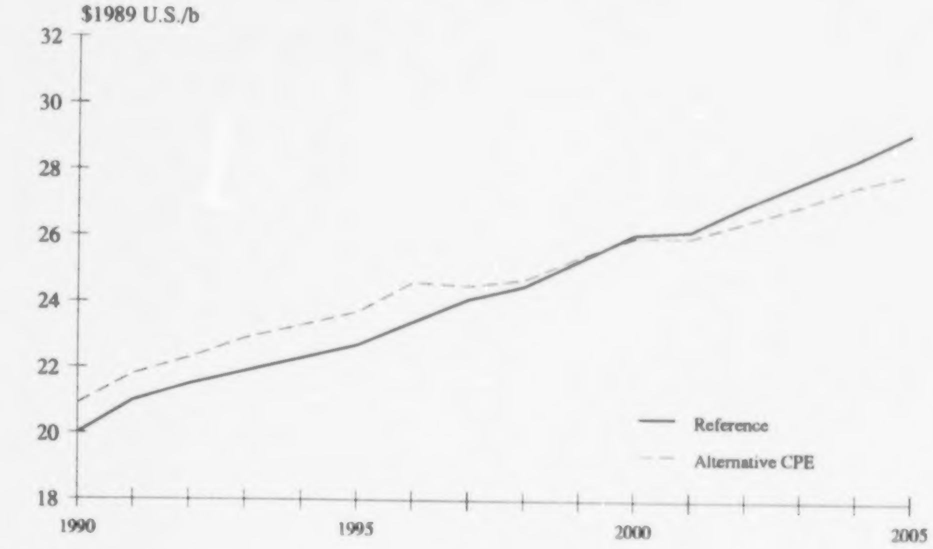
As discussed above, CPE crude oil production is not impacted significantly until late in the 1990s, when foreign capital and technology begin to show up in the form of higher production volumes. CPE crude oil production rises from 17 MMb/d in 1998 to over 20 MMb/d in 2005, versus a reference case level of 17.5 in 2005.

The impact of this profile of increases in crude oil demand and production on CPE net exports results in a decline in exports to around 500 Mb/d by the end of the 1990s, followed by a steady increase in net exports through the 2000-2005 period as production gains begin to outstrip demand growth. By 2005 the CPEs are placing some 1.7 MMb/d more crude oil on the international market than in the reference case.

The impact of this scenario on the world oil market is to slightly dampen real price gains and increase the absolute size of the oil market, relative to the reference case. As shown in Figure 3.11, crude price gains are slightly greater under the alternative scenario up to 1997-1998. After that point, the gradual increase in CPE production begins to exert downward pressure on prices, becoming more prominent in the next century. The crude oil price in 2005 under the alternative scenario is projected at roughly $28 (U.S.) per barrel, versus $29.20 under the reference case.

The growth in CPE refined petroleum product demand, combined with the price-induced gains in demand experienced elsewhere in the oil market, yields a global oil market in excess of 81 MMb/d in 2005. This compares with a reference case volume of 78.7 MMb/d. CPE crude oil production in 2005 accounts for just under 25 percent of global crude oil supply, versus 22 percent in the reference case. The production profile for the non-OPEC, non-CPE producers is virtually identical to that in the reference case, with end-of-forecast production volumes some 100 Mb/d lower under the alternative scenario in response to the slightly lower crude oil price track.

Figure 3.11
Alternative Scenario: CPE Region
World Oil Prices



SOURCE: CERI, January 1990.

Perhaps the element of greatest uncertainty within this scenario is the profile for CPE crude oil production, particularly beyond the late 1990s. The infusion of western financial capital and technology into the Soviet Union clearly presupposes a much altered social, economic and political reality than exists today, even with the current changes taking place under Premier Gorbachev. Given that an environment conducive to such East-West cooperation could, in fact, be brought about, there still remains considerable uncertainty regarding the volume and quality of undiscovered oil reserves in the Soviet Union.

To examine the impact of this uncertainty, a scenario was developed in which CPE production increased over time, but not sufficiently to offset the accelerated growth in CPE oil demand. Net exports from the region were projected to decline steadily to roughly 100 Mb/d by the year 2005. In this case, it is the growth in crude oil demand in the CPEs which plays the dominant role in affecting the evolution of the world oil market. Real crude oil prices are higher than in the reference case--reaching $30.60 (U.S.) per barrel by 2005 versus $29.20 in the reference case--and the world market itself is somewhat smaller than in the alternative scenario discussed above, due to the downward effect on world oil demand resulting from the higher price track.

The key conclusion to draw from these analyses is that developments in Eastern Europe and the Soviet Union over the 1990s may have a very significant impact on the development of the world oil market. The uncertainty regarding the direction of these impacts, as well as the magnitude, compounds the importance of careful research and analysis being directed towards a better understanding of the supply-demand fundamentals underlying the energy sectors of the centrally planned economies.

Footnotes

[1] For example, as of January 1, 1989 the *Oil and Gas Journal* estimates total proven world crude oil reserves at 990.6 billion barrels, while *World Oil* estimates a more conservative level of 923.7 billion barrels.

[2] As discussed in Section 2.2, roughly 94 percent of non-OPEC crude oil production is lifted at operating costs at or below $6.00 per barrel ($1985 U.S.).

[3] Much of the descriptive material in this section is abstracted from CERI Study 33, *Critical Issues in Electric Power Planning in the 1990s*, November 1989, Sections 6.2-6.3.

[4] Donald Renaud, "Public Appreciation of Energy Policy Issues" (Ottawa, Ontario: Energy, Mines and Resources Canada, Communications Branch, May 1988).

[5] Electric Power Research Institute, "The Politics of Climate," *EPRI Journal* (Palo Alto, California: EPRI, June 1988), p. 7.

[6] Workshops were held in Villach in September/October 1987 and in Bellagio in November 1987, under the auspices of the Beijer Institute, Stockholm, Sweden.

[7] The movement away from heavier refined products in particular regions is captured in the World Oil Market Model reference case, to a certain extent, through lower income elasticities relative to lighter products. In this section, the analysis refers to an additional tax levied against gasoline and heavy fuel oil, over and above the income elasticity adjustments.

[8] In Canada, CO_2 emissions from transportation and industrial activity excluding electricity generation are estimated to have accounted for 60 percent of total CO_2 emissions in 1985. See DPA Group, *Study on the Reduction of Energy-Related Greenhouse Gas Emissions, Volume 1*, March 1989, p. 10.

[9] This analysis ignores any income redistribution effects which may result from such a tax. Conceivably, the income generated from the tax could be redirected into research and development of clean fuel technologies and to incentives and/or subsidies designed to aid oil consumers in switching to alternative fuels. These initiatives would tend to further dampen petroleum product demand.

[10] Significant changes to crude oil supply could also result from greater environmental militancy. Billions of dollars of investment capital would be required to adequately gear up refineries to meet the shift in the product demand slate toward lighter refined products. Light crudes would also come under greater demand pressure. Supply of light crude oil is already rapidly diminishing in most non-OPEC countries, while alternative sources of light crude (e.g., upgrading facilities for heavy oil and bitumen) are not economic at the prices projected in this scenario.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

The world oil market of the 1980s will be remembered as a source of unprecedented instability and uncertainty in the global economy, touching virtually every element of economic and social planning in every part of the world. From the dizzying price levels of the early 1980s--and the unrealistic expectations for continued price gains--to the depths of the 1986 oil price crash, policy-makers and crude oil producers rode the roller-coaster of oil market uncertainty brought on by unexpectedly strong demand response to price and income changes and the success of non-OPEC countries in realizing the oil reserves potential existing outside of the OPEC world. These forces created the surplus capacity overhang which dominated energy sector planning and oil price developments over the last decade.

The projections provided in the preceding chapters suggest that the fragility of oil prices, which prompted unusual conservatism in oil sector exploration and development activity in the late 1980s, is likely to dissipate as we move through the 1990s. Slow but steady demand growth for refined petroleum products combined with a gradual decline in non-OPEC production should serve to tighten the supply-demand balance in the world oil market. With the current surplus capacity overhang worked off by the middle of the decade, the market would be poised for real price and/or OPEC production gains, the latter being increasingly concentrated in the Persian Gulf OPEC countries.

Placed against the supply-demand fundamentals are new uncertainties which can be expected to impact the global oil market. Foremost among these are the expected but uncertain actions forthcoming on behalf of the global environment. Concerted actions on a global basis directed toward the reduction of atmospheric and greenhouse gas emissions could result in a replay of the energy conservation, efficiency and off-oil initiatives of the early 1980s, but this time driven by fiscal initiatives rather than market-responsive prices.

Elsewhere, the efforts of the developing countries toward industrialization and economic growth are a continuing source of pent-up energy and petroleum products demand. The dramatic political and social changes in Eastern Europe and the Soviet Union could have major impacts on the world energy markets, through both increased energy demand and greater exploitation of the hydrocarbon reserves resident in those regions. Lying behind all of these developments is a growing concern over the financial ability of the OPEC nations to increase productive capacity in order to meet the demand growth anticipated for the latter 1990s and to thereby avoid another high oil price cycle.

4.1 Reference Market Projections

The reference case oil market projections provided in Chapter 2 reflect a most-likely development scenario for world oil prices, abstracting from the key uncertainties referenced above. **The principal message arising from this projection is that the world oil market will attain a tighter supply-demand balance by the mid-1990s, reintroducing the potential for engineered real price gains through the latter half of the decade and into the next century**. The reference case oil price path is based on an OPEC strategy of gradual real price and production gains over the forecast period. This yields a somewhat lower oil price path and larger market size than projected in *Stability Within Uncertainty*.

In many respects, this reference case projection represents a "best-case" scenario for all oil market players. For OPEC members, the price-production profile allows for steady near-term revenue growth through output quota gains, and longer-term revenue growth through both price and output gains. Annual oil revenue accruing to OPEC more than doubles over the forecast horizon, from $160 billion in 1990 to $386 billion in 2005 (constant $1989 U.S.). In present value terms, OPEC would realize over $2 trillion from crude oil sales over the 15-year period, assuming a 10 percent rate of discount. **This revenue profile is equivalent or superior to the revenue profiles generated under the numerous sensitivity analyses and alternative scenarios generated in this research program, reinforcing the strategic importance of a sustained, gradual price-production growth strategy for OPEC.**

For non-OPEC producing countries, the real price gains through the 1990s are sufficient to justify development of existing established reserves and exploration activity directed to the more promising prospects and plays. However, prices do not reach a level sufficient for development of grassroots frontier and nonconventional crude oil sources (e.g., integrated mined oil sands, two-stage coal liquefaction) until late in the forecast period. For the consumer, real crude oil price increases of 2.0 to 3.5 percent per year do not constitute an important cost-push element to general price inflation. Indeed, these projected price gains are generally below those forecast for other energy commodities (particularly natural gas and electricity) in the industrialized countries over the projection period.

The reference case OPEC production profile contains an implicit assumption that Organization members will be able to increase productive capacity in order to service the rising call on OPEC crude, particularly in the 2000-2005 period. **While there is no argument that OPEC possesses the physical reserves to meet rising world oil demand, there is growing concern that the Organization may lack the financial reserves to undertake the required facilities expansion.** The severe national debt problems facing many OPEC member nations have made the prospect of discretionary fiscal weakness within OPEC a very real concern. One possible outcome arising from this situation is a modest re-integration between the multi-national oil companies and those OPEC members amenable to joint venture capital in the development of domestic reserves.

In summary, the reference oil price projection is dependent on continued OPEC production restraint, particularly over the next 4 to 5 years. Beyond the mid-1990s, the combination of steady petroleum product demand growth and declining non-OPEC production turns the world oil market increasingly toward the OPEC nations and, in particular, the reserves-rich Persian Gulf countries. The medium- to long-term benefits awaiting the Organization should outweigh the near-term revenue temptation associated with rapid production or price increases, yielding a market that becomes more stable as we move through the 1990s and into the next century.

4.2 Assessing the Uncertainties

Chapter 3 provided a detailed examination of a number of key uncertainties in the world oil market. The high non-OPEC resource scenario examined the impact on the reference case projection of a larger non-OPEC reserves base. The results suggested that such a scenario would yield lower crude oil prices over a longer period of time than under the reference case. For OPEC, this scenario would clearly exacerbate the divisions within the Organization regarding pricing and production strategies. To maintain revenue at the levels associated with the reference case scenario would require greater OPEC production, resulting in much lower prices. To maintain prices at the levels associated with the reference case would require much lower OPEC production, exacerbated by the supply response from the non-OPEC regions. The risk of a crude oil price collapse under this scenario would be much greater than under the reference case, as would the probability of a collapse in the Organization down to a smaller group of nations characterized by large crude oil reserves and the ability to achieve and maintain high production levels.

The high non-OPEC resource scenario is a legitimate alternative to the reference case projection, whether the high non-OPEC production levels are deemed to be associated with a larger reserves base or with advances in oil sector technology. Continued gains in seismic and drilling technology, which lower the hurdle price for new field development, would tend to accelerate non-OPEC production gains. Advances in enhanced oil recovery techniques, aimed at accessing the roughly 50 to 60 percent of original oil-in-place remaining after exhaustion of primary and secondary drive, and cost reductions in nonconventional oil liquids technologies would further add to non-OPEC production capacity.

The examination of alternative OPEC price-production strategies concluded that, from a revenue standpoint, the Organization would benefit equally from a near-term price gain or near-term production gain strategy, and that the present value of the resulting revenue streams would be virtually identical to that of the reference projection, at roughly $2.0 trillion (assuming a 10 percent discount rate). **However, the choice of price-production strategy has a very marked impact on the evolution of the world oil market and on the type of market OPEC would face at the start of the next century.** Under a near-term price gain strategy, OPEC would create a market that is growing as we enter the next century. Under a near-term production gain strategy, OPEC would see a market in decline, albeit from a larger size in the 1990s. Under the reference case price-production strategy, the Organization would see a market that is both larger and gradually expanding. **Again, the combination of gradual price and production gains through the next decade would appear to be a dominant OPEC strategy in terms of market share and market size, even if it is revenue neutral in comparison to the alternative price-production strategies.**

Two additional scenarios were examined, dealing with uncertainties which could significantly alter the assumptions underlying the scenarios discussed above. The first dealt with the growing global concern over atmospheric emissions, the second with the dramatic events unfolding in the Soviet Union and Eastern Europe.

4.2.1 Environmental Initiatives

To fully address the question of reduction of atmospheric emissions on a global basis clearly requires a comprehensive energy end-use model, flexible enough to examine the fuel substitution and energy use impacts of a wide range of fiscal and emission guideline options. While the CERI World Oil Market Model falls short of this objective, it is useful in examining the potential impact of the imposition of end-use taxes on petroleum product demand and, hence, on world oil prices.

The scenario examined in Chapter 3 assumed the application of a 10 percent product tax on transportation fuels and heavy fuel oil, levied at the burner tip. The tax was assumed to be phased in across the industrialized countries over the 1990-1995 period.

It was further assumed that for various political, social and financial reasons, no equivalent action would be taken by the developing countries. This reflects the view that the developing countries, still struggling to attain the level of economic wealth achieved by the industrialized countries in part through the unfettered exploitation of global hydrocarbon reserves, would not agree to jeopardize their growth potential through reduction in energy use, regardless of the potential consequences of global warming and continued environmental degradation. Rather, the solution to the buildup of greenhouse gas emissions would be left to those nations that had benefitted from the creation of the problem.

The key scenario result is that national and regional initiatives to reduce oil product consumption, for environmental or other reasons, will not be successful unless all nations are involved in the process. Gains made in one jurisdiction in reducing petroleum product demand will show up, through the oil market, as price-driven incentives to increase petroleum product consumption in other regions. **In the absence of global cooperation, such a piecemeal approach to the reduction of hydrocarbon consumption would have little impact beyond generating considerable revenue to those governments pursuing such fiscal initiatives, and transferring**

a cost of production and terms of trade advantage to those who chose not to implement those initiatives.

4.2.2 Soviet Union and Eastern Europe

The social, political and economic upheaval currently ongoing in the Soviet Union and Eastern Europe is destined to have profound implications for every facet of the global community, including the world energy markets. Analysis of the potential impact of glasnost and perestroika on Soviet and Eastern European economic developments, on energy demand and supply, and on the net crude oil export position of the CPEs in the world oil market is further complicated by the directional uncertainty of these developments in affecting the world oil market.

On the demand side, support from the industrialized countries through, for example, the provision of financial and human capital to support accelerated industrialization of the Soviet Union and Eastern European economies would lead to stronger energy (and petroleum product) demand growth than envisaged under the reference case. Deployment of older production processes and technologies, which tend to be more energy intensive, would reinforce this demand profile. On the supply side, outside involvement in the development of Soviet energy resources---particularly in the form of imported technology--could accelerate significantly the production and export capability of the Soviet Union.

The scenario examined in Chapter 3 is only one of many possible outcomes resulting from this unprecedented political upheaval. As events unfold, it will become possible to better gauge the magnitude of competing forces impacting the energy sector in these countries. It is clear, however, that careful research and analysis must be directed towards a better understanding of the supply-demand fundamentals underlying the energy sectors of the centrally planned economies.

4.3 Future Research

The Canadian Energy Research Institute has in place an ongoing research program directed towards the refinement and enhancement of the World Oil Market Model and the identification and analysis of key variables impacting on the evolution of the world oil market. To date, the majority of research effort has been directed towards the disaggregated representation of non-OPEC producing countries within the WOMM.

Over the next twelve months, the research effort will focus on the demand side of the oil market, further disaggregating the regional assessment of petroleum product demand and investigating the incorporation of explicit interfuel substitution capabilities within the framework. A separate research agenda will focus on developments in the Soviet Union and Eastern Europe, with the objective of incorporating the findings into the WOMM.

The enhanced WOMM framework will be employed in preparing the third in the CERI series of world oil market studies, scheduled for June 1991. Users of the World Oil Market Model and other interested parties are encouraged to forward their comments and input regarding the WOMM and world oil research programs to the Institute.

APPENDIX A

DESCRIPTION OF THE CERI WORLD OIL MARKET MODEL

Appendix A

DESCRIPTION OF THE CERI WORLD OIL MARKET MODEL

A.1 Introduction

In September 1988, CERI released Study No. 28, *Stability Within Uncertainty: Evolution of the World Oil Market*. The centerpiece of this forward looking analysis was the application of a computer model to project future world oil consumption, supply and prices under several plausible market scenarios. The initial version of this model was developed by CERI over the prior 2 years and is commonly referred to as the CERI World Oil Market Model (WOMM). The latest version of the WOMM, Version 3.1, has been enhanced significantly as part of the Institute's commitment to a continued body of research on the world oil market and its impact upon planners and policy makers.

An important objective of the Institute is to aid its sponsors in the medium- to long-term planning process, a key element of which is the assessment of likely trends in future oil prices and the identification and analysis of the key uncertainties underlying these prices. **Therefore, in addition to regularly published updates on world oil market projects, the Institute has made the WOMM software available exclusively to its sponsors**. This appendix is designed to provide the general public and prospective model users with an overview of the structure of the WOMM. As a great deal of the conceptual background and justification for the existing WOMM framework is provided in CERI Study No. 28 (hereafter referred to as the World Oil Market Study or WOMS), this appendix will refer the reader to appropriate sections therein.

The WOMM consists of two primary components:

(i) The CERI World Oil Demand Model (WODM); and

(ii) The CERI World Oil Supply Model (WOSM).

These components can be run on a stand-alone basis by specifying an endogenous price track over the forecast horizon (along with a number of other key inputs described below). This feature allows the user to examine the sensitivity of world oil demand and supply to various assumptions concerning oil prices, economic growth, interest rates, resource bases, and so on.

The primary motivation behind development of the WOMM was, however, to provide an integrated projection of either of two critical variables:

(i) world oil prices, defined to represent West Texas Intermediate (WTI) prices at Cushing, Oklahoma, expressed in constant 1988 U.S. dollars; or

(ii) OPEC production levels, which represent total crude oil production by the Organization.

Section A.2 deals specifically with the methodologies and parameters of the WODM. Section A.3 describes the WOSM with particular attention to the Drilling Activity, Reserves Additions, Production, and Cost submodels. Section A.4 concludes with a summary of the integrated World Oil Market Model.

A.2 The World Oil Demand Model (WODM)

The WODM utilizes an approach which is commonly referred to as the bottom-up methodology. The model first characterizes the demand for the major types of refined petroleum products in a particular region as a function of the price of that product and some measure of economic growth. Total regional crude oil demand is then calculated by aggregating the various product demands. Total world oil demand is calculated by aggregating the various regional demands. The major benefit of this approach is the ability to distinguish demand behaviour between different products and between different regions. Chapter 2 of the WOMS goes into considerable detail about alternative approaches, their particular strengths and weaknesses, and the reasoning behind our choice of the bottom-up methodology.

In the WODM the world is divided into seven consuming regions:

1. Canada;
2. United States;
3. Western Europe;
4. Australasia (Japan, Australia and New Zealand);

5. Less Developed Countries (LDC's), excluding OPEC member nations;
6. OPEC member nations; and
7. Central Planned Economies (CPE's).

Within each of these consuming regions, product demand equations are specified for four major groupings of refined petroleum products:

1. Gasoline (including aviation fuels);
2. Middle distillates (including automotive diesel fuels);
3. Heavy fuel oils; and
4. Other products (including non-energy products, refinery fuel and losses).

Thus the demand side of the CERI World Oil Market Model specifies a total of 28 different refined product demand equations: one for each of the above product groupings in each of the seven demand regions.

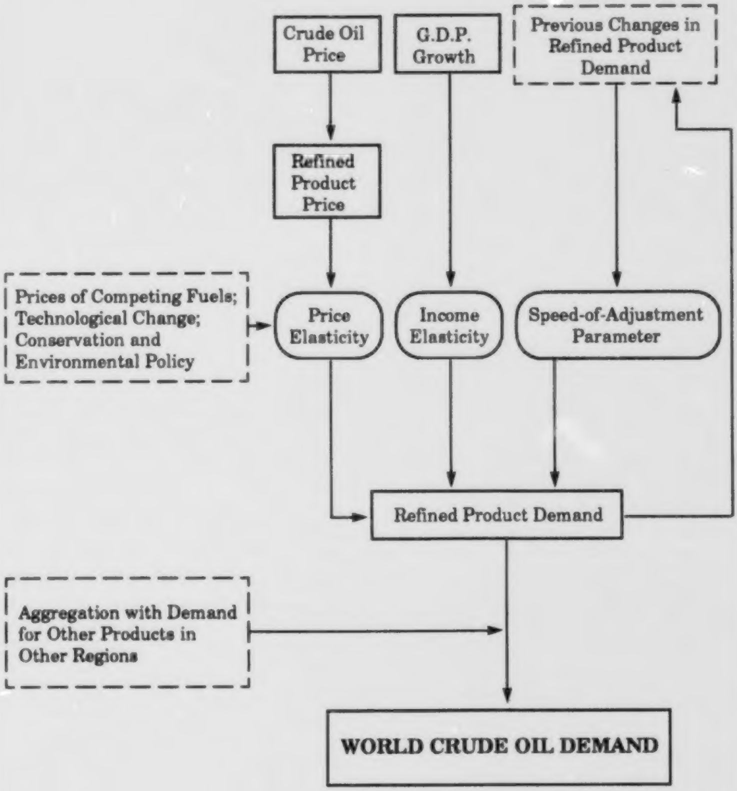
Figure A.1 provides a simple schematic view of the WODM. In each equation, product demand is a function of two exogenous variables: the price of the refined product and a regionally disaggregated forecast of economic growth. To account for the lagged effects of previous changes in oil prices and national income, a third variable--previous changes in product demand--is also considered by the equation. The result is the autoregressive, Koyck-transformed constant-elasticity demand equation that is widely accepted by demand analysts[1]:

$$D_t = a(P_t)^b(Y_t)^c(D_{t-1})^{1-d} \qquad (1)$$

where:

D_t = product demand at time t
P_t = product price
Y_t = national income
D_{t-1} = lagged product demand
a = a constant
b = short-term price elasticity
c = short-term income elasticity
d = speed-of-adjustment parameter

Figure A.1
Schematic View of the
World Oil Demand Model


Crude Oil Price
G.D.P. Growth
Previous Changes in Refined Product Demand
Refined Product Price
Prices of Competing Fuels; Technological Change; Conservation and Environmental Policy
Price Elasticity
Income Elasticity
Speed-of-Adjustment Parameter
Refined Product Demand
Aggregation with Demand for Other Products in Other Regions
WORLD CRUDE OIL DEMAND

SOURCE: CERI.

A change in either price or Gross Domestic Product (GDP) will affect product demand in the current year according to the magnitude of the short-term coefficients a and b. The cumulative effect of a change in either of the exogenous variables can be considered by calculating the long-term price and income elasticities:

`long-term elasticity =`
`(short-term elasticity)/d` (2)

The speed-of-adjustment parameter, d, always falls between 0 and 1. The closer d is to 1, the faster is the adjustment of demand to changes in price and income, and the less important will be the lagged effects of previous changes in the exogenous variables.

As described in Section 2.4.3 of the WOMS, the choice of values for the parameters of each demand equation--price elasticity, income elasticity and speed-of-adjustment parameter--will have an important effect on the forecast levels of refined product demand. When the research for the demand side of the WOMM was initiated, a wide range of econometric studies of refined product demand in various regions was surveyed.[2] It became clear that there existed no widespread agreement as to either the precise form of an appropriate product demand equation, or the correct values of the respective price and income elasticities. The results of the various econometric analyses depended greatly on the specific data series employed and the structure of the demand equations estimated in each case.

There is no reason to believe that our own econometric estimates of refined product demand should be any more reliable than those of the dozens of econometric specialists who have also published their results. Rather than trying to replicate and improve upon this published work, we have instead chosen the most popular demand specification from amongst the various studies (the standard log-linear equation described above) and have selected elasticity estimates that are representative of the large sample of previous econometric work that we consulted. The flexibility of our modelling structure then allows us to test for the effects of changes to our selected slate of product demand parameters. In Version 3.1 of the WOMM, these parameters remain unadjusted.

The elasticity estimates used in the reference case runs of the WOMM are detailed in Table A.1. Price elasticities are higher (in absolute terms) and speed-of-adjustment rates faster in the developed market economies, where it is assumed that a more sophisticated

TABLE A.1

PRODUCT DEMAND PARAMETERS

Region and Product	Short-Term Price Elasticity	Short-Term Income Elasticity	Speed-of-Adjustment Parameter
All OECD Countries			
Gasoline	-.1000	.1500	.2000
Middle Distillates	-.2250	.1000	.3000
Heavy Fuel Oil	-.3500	.0500	.4000
Other Products	-.1250	.1500	.2000
Less Developed Countries			
Gasoline	-.0975	.1500	.1500
Middle Distillates	-.1500	.2000	.2000
Heavy Fuel Oil	-.2000	.2500	.2500
Other Products	-.1000	.1000	.1500
OPEC			
Gasoline	-.0750	.1875	.1500
Middle Distillates	-.1200	.2500	.2000
Heavy Fuel Oil	-.1500	.3000	.2500
Other Products	-.0500	.1250	.1000
Centrally Planned Economies[a]:			
Gasoline	.0000	.3750	.7500
Middle Distillates	.0000	.2812	.7500
Heavy Fuel Oil	.0000	.2812	.7500
Other Products	.0000	.3750	.7500

SOURCE: Canadian Energy Research Institute.

[a] In the Centrally Planned Economies, all price elasticities are set to zero, since consumption is determined by plan and not by market forces. The speed of adjustment factor is consequently higher for all products, as adjustment to changes in income are not a function of time lags to the same degree as are adjustments to price shocks.

capital stock and flexible market structures allow for a faster and larger adjustment to changes in relative energy prices. Income elasticities are higher in the developing countries, where the relationship between oil demand and economic growth is more direct. Price elasticities are larger (in absolute terms) for the heavier refined products--especially for heavy fuel oil--due to stronger competition from alternative fuels in the industrial and utility markets. Income elasticities are lower for these same products, reflecting a long-term trend away from heavier products for environmental and other reasons.

The speed-of-adjustment parameter is very high for the Centrally Planned Economies, since it is assumed that there is no direct relationship between world oil prices and CPE oil consumption. Economic growth, therefore, is the only determinant of oil demand in the CPEs. Economic expansion has a faster and more direct impact on oil demand than does a change in price, and it is, therefore, reasonable to expect that the lagged effect of previous changes in the exogenous variables will not have as significant an impact on product demand in the CPEs relative to the other demand regions.

As described above, the refined product demand equations used by the WOMM utilize two exogenous variables: the price of the refined product in question, and a measure of regional economic growth. The supply/demand model as a whole, however, is designed to interact through a single world oil price, not a series of regional refined product prices. The model requires a mechanism, therefore, to convert the world crude oil price into the final end-use product prices that influence the level of refined product consumption.

The theoretical relationship between crude price and product prices is discussed in Section 2.3.1 of the WOMS. Transportation costs, refining costs, distributors' margins, and taxes must be added to the price of crude oil feedstock in order to determine the price paid by the final consumer. If consistent data on each of these components of refined product prices could be gathered, and if those values could be exogenously forecast for future years, then the product price-crude price relationship could be explicitly modelled. In reality, however, a more approximate approach must be taken, since data on the various components of product prices is simply not detailed enough to allow for such precise calculations.

We have assumed that final product prices will depend on the world crude oil price in a straightforward linear fashion as follows:

`Product Price = v + w*(Crude Price)` (3)

The constant v can loosely be interpreted as representing fixed processing costs, transportation costs, and taxes. The parameter w , on the other hand, reflects the variable costs of world oil feedstock, unstable distributors' margins, and value-added taxes.

Utilizing historical data on final refined product prices in various countries,[3] three pooled cross-sectional time-series regressions were performed to derive rough estimates of these two parameters. These estimates are listed in Table A.2 together with the corresponding R^2 values resulting from the regressions.

The primary weakness associated with this interpretation of the product price-crude price relationship is that it assumes that changes in crude oil prices are the only cause of changes in end-use product prices. Future changes in government taxes or changes in refining and distributing margins which could have an equally significant impact on final prices, are not captured in this framework. It is impossible, however, to forecast these changes in the non-oil components of refined product prices, so for a forecasting model of the world oil market the simplified approach described above is the most feasible option.

A.3 The World Oil Supply Model (WOSM)

The WOSM employs the traditional analysis of reserves additions to project production rates. Crude oil is supplied to the world oil market through three major groups: the Organization of Petroleum Exporting Countries (OPEC); the non-CPE competitive fringe; and CPE net exports. Due to the lack of any reliable method to accurately model supply behavior of individual members of OPEC, the WOMM utilizes an exogenous production track to project total OPEC production. Likewise, a projection of production is required to estimate future net exports for the CPEs (i.e., Russia, China, and Eastern Europe).

The following discussion of supply side methodology pertains specifically to the non-CPE competitive fringe producing regions which include:

1. Canada
2. the United States

TABLE A.2

PRODUCT PRICE - CRUDE PRICE PARAMETERS

Region and Product	Constant Factor (v)	Variable Factor (w)	R^2
Canada:			
Gasoline	15.00	2.00	.95
Middle Distillates	12.50	1.75	.90
Heavy Fuel Oil	2.75	1.25	.90
Other Products[a]	30.00	2.00	na
United States:			
Gasoline	15.00	1.50	.95
Middle Distillates	12.50	1.50	.90
Heavy Fuel Oil	2.75	0.80	.90
Other Products[a]	30.00	1.50	na
Western Europe:			
Gasoline	35.00	2.00	.95
Middle Distillates	20.00	1.75	.80
Heavy Fuel Oil	2.75	0.80	.95
Other Products[a]	50.00	2.00	na
Pacific OECD:			
Gasoline	25.00	2.00	.95
Middle Distillates	10.00	1.75	.95
Heavy Fuel Oil	3.25	0.90	.95
Other Products[a]	40.00	2.00	na
Less Developed Countries:			
Gasoline	20.00	1.80	.95
Middle Distillates	10.00	1.25	.95
Heavy Fuel Oil	3.25	0.70	.90
Other Products[a]	35.00	1.80	na
OPEC:			
Gasoline	7.50	0.50	.60
Middle Distillates	5.00	0.25	.30
Heavy Fuel Oil	2.25	0.25	.80
Other Products[a]	22.50	0.50	na
Centrally Planned Economies:[b]	na	na	na

SOURCE: Canadian Energy Research Institute.

[a] Regressions for the "other products" category could not be run due to a lack of product price data. These parameters were derived by using the same variable factor (w) as for gasoline, and the same constant factor (v) as gasoline plus a margin of 15.00, reflecting higher processing costs.

[b] In the Centrally Planned Economies, all price elasticities are set to zero, since consumption is determined by plan and not by market forces. There is no need to specify the parameters of the product price-crude price equations.

3. Mexico
4. Brazil
5. Argentina
6. Colombia--also includes Bolivia and Chile
7. Peru
8. Trinidad
9. Egypt--also includes Tunisia
10. Angola--also includes the Congo, Cameroon and Zaire
11. India--also includes Pakistan and Burma
12. Malaysia
13. Australia--also includes New Zealand
14. Other Middle East--includes both North and South Yemen, Oman, Syria and Israel
15. North Sea
16. Western Europe

The WOSM consists of 4 submodels:

(i) a **Drilling Activity** submodel;

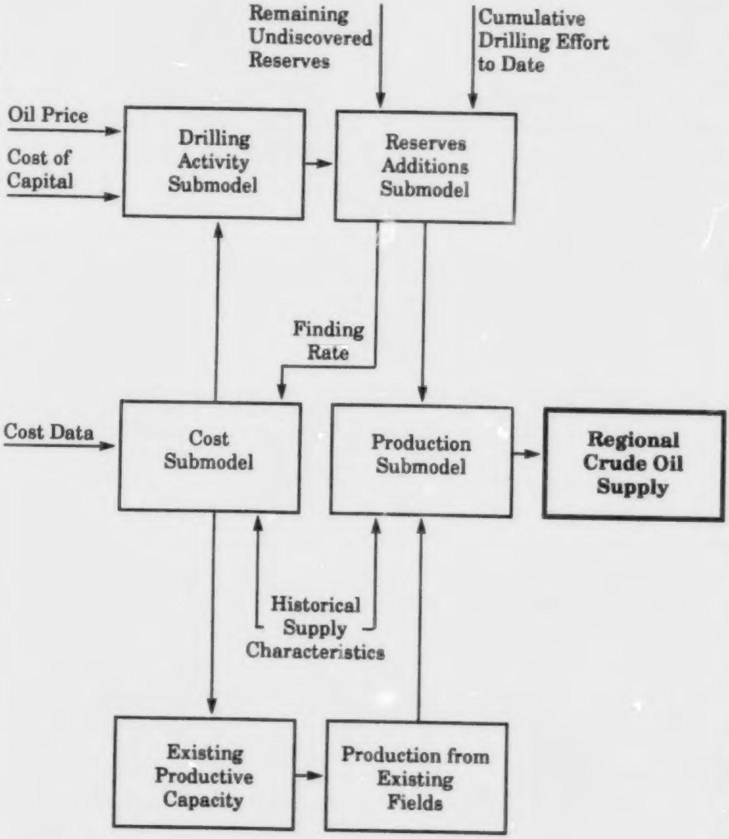
(ii) a **Reserve Additions** submodel;

(iii) a **Production** submodel; and

(iv) a **Cost** submodel.

The interaction of these submodels to project crude oil production in any of the above regions is portrayed in Figure A.2. As illustrated, the driving force behind each region's time path of oil production is the level of drilling activity. The projected level of drilling activity then feeds into the reserves additions submodel to determine the pace of future reserves additions. The production submodel takes the level of reserves additions and generates a production profile over time based on the region's historical supply characteristics. It then adds production from existing fields to project a region's total productive capacity. The cost submodel calculates a weighted average, full cycle replacement cost based upon reservoir and capital cost characteristics unique to each region. The discussion below focusses

Figure A.2
Schematic View of the World Oil Supply Model


Remaining Undiscovered Reserves
Cumulative Drilling Effort to Date
Oil Price
Cost of Capital
Drilling Activity Submodel
Reserves Additions Submodel
Finding Rate
Cost Data
Cost Submodel
Production Submodel
Regional Crude Oil Supply
Historical Supply Characteristics
Existing Productive Capacity
Production from Existing Fields

SOURCE: CERI.

entirely on the structure and specification of each of these 4 submodels as well as the key underlying assumptions.

A.3.1 The Drilling Activity Submodel

The Drilling Activity submodel utilizes an econometric approach to project drilling activity by region. Section 3.3.1.1 of WOMS provides a brief review and references of some previous applications of this generic type of approach. Quite notably, nearly all of these studies focussed on very mature supply regions like the U.S and Canada.[4] In attempting to extend the basic approach to regions around the world, we were forced to deal with the realities of limited and poor quality data outside of the OECD countries. A number of simplifying assumptions were therefore required to make the task analytically tractable. First, drilling equations were estimated for total drilling activity measured in footage. Thus, no distinction is made between gas directed and oil directed drilling activity, or between exploratory and development drilling. Historical data on annual drilling footage by region was obtained from the *World Oil* magazine.

Second, drilling equations were estimated as a function of the following variables:

(i) A representative measure of world crude oil price (OP) to proxy the expected profitability of oil production. The coefficient on this variable captures the impact of changes in oil prices on drilling levels. Clearly, the preferred measure is a producer netback. However, we were restricted to using a world price series because a comprehensive compilation of fiscal and cost data across all producing countries was considerably beyond the scope of this analysis. The price variable is constructed by obtaining a price series for a representative crude type (Saudi Arabia light-34, obtained from Petroleum Intelligence Weekly; official crude prices until 1978, spot prices thereafter) and deflating it by the U.S. consumer price index.

(ii) The U.S. long-term corporate bond rate (OC) to proxy the opportunity cost of drilling activity and the cost of debt. If efficient capital markets are assumed, then this series should provide an adequate approximation of the cost of capital.

(iii) The reserves life index (UR) to proxy the utilization rate of reserves. A high reserves to production ratio is indicative of ample reserves at existing production levels, and signals a less urgent need for drilling activity. Conversely, a low reserves to production ratio signifies potential future supply shortages and creates an incentive to drill.

The general form of these drilling equations can be expressed as:

$$DA = f(OP,\ OC,\ UR) \tag{4}$$

A variety of functional forms was considered as approximations to the above equation. In the end, a simple linear specification was chosen on the basis of its simplicity, ease of interpretation and better overall fit. Thus the form of the estimated equations is as follows:

$$DA = a_0 + a_1{*}OP + a_2{*}OC + a_3{*}UR \tag{5}$$

This equation was estimated for each of the supply regions, for the period 1960 to 1984, using OLS regression. Table A.3 summarizes these estimates for the various supply regions along with the associated t-statistics (in brackets) and R^2 values. A zero indicates that the variable was not included in the estimated equation. In Version 3.1 of the WOMM, the equation parameter estimates remain unaltered.

In many instances the fit of these equations is relatively poor, stemming primarily from the lack of country-specific information required to construct a profitability, or netback, time series. It is also the case that this particular approach is more conducive to analysis of decision-making within private companies, as opposed to crown or national corporations. As such, the methodology may not accurately represent the drilling decision process in many OPEC and Third World countries. It is important to stress, however, that the primary objective of the drilling model is to project average drilling activity over time by region. By incorporating the world oil price into the model, it is possible to capture the impact of changing prices on the average level of drilling activity.

A.3.2 The Reserves Additions Submodel

A number of different methodologies have been developed to project the amount of petroleum resources that might be discovered in a particular region.[5] The approach we have chosen is loosely classified as "rate of effort" and is closely related to the pioneering work of

TABLE A.3

ESTIMATED PARAMETERS FOR DRILLING EQUATIONS

Supply Region	a_0	a_1	a_2	a_3	R^2
Canada	9 524.2	1 080.1	-123.9	-47.5	0.69
	(2.07)	(2.33)	(-1.62)	(-1.31)	
United States	124 633.6	13 701.5	18 989.72	0	0.71
	(7.07)	(5.21)	(-2.99)		
Mexico	3 101.4	95.9	-286.3	0	0.40
	(4.84)	(1.73)	(-2.05)		
Brazil	3 585.8	44.6	0	0	0.54
	(7.33)	(2.02)			
Argentina	8 264.1	248.9	-829.7	-98.3	0.58
	(4.86)	(3.98)	(-3.38)	(-1.82)	
Colombia	3 198.2	48.6	-128.1	0	0.33
	(5.85)	(2.79)	(-2.07)		
Peru	760.0	29.6	0	-32.3	0.72
	(4.71)	(6.23)		(-2.90)	
Trinidad	1 497.3	16.3	-113.8	0	0.68
	(14.87)	(2.94)	(-5.27)		
Egypt	1 589.9	13.8	0	-6.14	0.60
	(3.47)	(4.63)		(-2.50)	
Angola	300.7	27.1	0	0	0.53
	(4.86)	(5.00)			
India	3 218.8	35.8	-29.5	0	0.68
	(8.31)	(1.91)	(-2.01)		
Malaysia	956.7	10.7	0	0	0.31
	(18.71)	(2.45)			
Australia	109.7	81.3	0	0	0.62
	(1.93)	(1.52)			
Other Middle East	1 308.7	47.2	0	0	0.69
	(3.05)	(7.05)			
North Sea	1 040.5	85.4	0	0	0.86
	(2.45)	(4.78)			
Western Europe	8 122.1	213.0	-905.9	0	0.72
	(11.45)	(6.59)	(-7.38)		

SOURCE: Canadian Energy Research Institute.

M. King Hubbard.[6] Hubbard developed the "life cycle" concept of a fossil fuel to generate not only an estimate of what ultimately will be discovered in a region, but also the time path of rates of discovery and production. "Rate of effort" models differ in that they generate estimates of rates of discovery and production as a function of cumulative exploratory effort, rather than time. This provides a direct link between the drilling and reserves additions submodels, and allows us to project reserves additions as a function of price.

The "rate of effort" approach requires the fitting of a cumulative growth curve to historical data on cumulative discoveries and drilling activity. The slope of the growth curve represents the rate of discovery, more commonly known as the finding rate and defined in this case to be the reserves added in any year divided by total feet drilled in that year.

Historical data on finding rates show wide fluctuations on a yearly basis. However, some important general trends can be observed. Examination of the data suggests that our representation of the discovery process should reflect the following temporal pattern:

(i) In relatively unexplored regions, finding rates may initially increase over time as knowledge of the region's geology is accumulated and drilling efforts show the product of this increased knowledge;

(ii) At some point in time as the cumulative level of drilling in a region increases, the returns to drilling will begin to diminish. This is supported by the widely accepted hypothesis that the underlying distribution of pool sizes is lognormal. Thus, the larger pools will tend to be discovered early in the exploration process. The trend of discoveries is a declining pool size range which is a function of the lognormal pool size distribution; and

(iii) Eventually, the finding rate will decline to zero as the total amount of reserves discovered approaches the region's ultimate potential.

A functional form which meets these general criteria is the logistics function which can be expressed as follows:[7]

$$CD_t = UP*(1 - (B*e^{-A*X_t})) \qquad (6)$$

where:

CD_t = cumulative discoveries in year t

UP = ultimate potential

X_t = cumulative drilling footage to year t

A, B = estimated parameters

For estimation purposes, equation (6) can be transformed into the following form:

$$Ln(UP/CD_t - 1) = Ln(B) - (A*X_t) \tag{7}$$

This estimation procedure requires data on cumulative feet drilled, cumulative discoveries, and ultimately recoverable crude oil resources by region. Data from the *World Oil* magazine is used to construct time series for the first two variables. Estimates of undiscovered recoverable oil resources at three different probability levels were obtained from a number of sources to generate estimates of ultimate resource potential for each supply region.[8] The high degree of uncertainty associated with these estimates is addressed by fitting equation (7) using these ranges of ultimate potential (see Appendix D of the WOMS for an illustration of this approach, using Egypt as a case study).

As discussed above, an expression for calculating finding rates can be derived from equation (6) by differentiating it with respect to cumulative footage to yield:

$$dCD_t/dX_t = FR_t = \frac{(B*A*UP*e^{-A*X_t})}{(1 + B*e^{-A*X_t})^2} \tag{8}$$

where:

FR_t = the finding rate in year t (b/ft)

In some regions, there was either insufficient data to carry out this procedure, or the fit of the equation was poor. In these instances a somewhat simpler representation of finding rates was employed. This representation, however, embodies the principal elements described above and is written as follows:

$$FR_t = FR_{t_o}*e^{-((FR_{t_o}/DR_t)*X_t)} \tag{9}$$

where:

FR_{t_0} = initial finding rate

DR_t = undiscovered resource left in year t

X_t = cumulative drilling to year t

For Version 3.1 of the WOMM, the parameters underlying equation (8)--A, B, and the ultimate potential--were updated and are provided in Table A.4 for each supply region. Note that the equation employed in each region is specified by its number.

Once the parameters describing the finding rate equations have been determined for each supply region, they are used to project future finding rates as a function of forecast drilling activity. The estimated finding rates in any year are then multiplied by that year's forecasted drilling activity to yield an estimate of expected reserves additions.

A.3.3 The Production Submodel

In all oil fields, the rate of production eventually enters into a period of decline due to pressure loss in the producing formation (this rate of decline can be mitigated by the use of enhanced oil recovery techniques). In the initial years of production, however, a period of flat or even increasing production is possible. This varies considerably by field as does the subsequent rate of decline, depending on the regulatory environment, the operator's production strategy, the geological characteristics of the producing formation, and the drive mechanism.

The crude oil productive capacity in any region is determined as the sum of production from existing fields and new production brought on stream through reserves additions. In the former case, the rate of decline in any region is approximated on an aggregate basis using the widely held assumption that decline rate is equal to the ratio of annual production to reserves, as would be true under conditions of exponential decline. For new production from reserves additions, a degree of flexibility was introduced by allowing the user to specify production profiles for future reserves additions in any region, based on specialized knowledge that might be available about the producing characteristics of that region. This feature is an attempt to deal with the following uncertainties:

(i) the pace of development for future reserves additions. For example, in a developing country one might not see a new discovery reach peak

TABLE A.4

ESTIMATED PARAMETERS FOR FINDING RATE EQUATIONS

Supply Region	Equation	Ultimate Potential (MMb)	A (FR_{to})	B
Canada	9	22 200	14	--
	9	24 636	14	--
	9	26 523	14	--
United States	9	179 000	10	--
	9	197 000	10	--
	9	219 000	10	--
Mexico	8	83 500	7.94 (10^{-8})	7.40
	8	108 000	6.58 (10^{-8})	6.70
	8	227 000	5.38 (10^{-8})	6.68
Brazil	8	7 366	4.71 (10^{-8})	2.03
	8	9 000	4.14 (10^{-8})	2.18
	8	12 600	3.60 (10^{-8})	2.48
Argentina	8	7 500	1.93 (10^{-8})	1.17
	8	8 500	1.58 (10^{-8})	1.20
	8	12 152	1.13 (10^{-8})	1.51
Colombia	8	7 874	3.44 (10^{-8})	0.79
	8	9 500	2.75 (10^{-8})	0.98
	8	13 500	2.15 (10^{-8})	1.39
Peru	8	3 048	5.71 (10^{-8})	1.46
	8	3 600	4.95 (10^{-8})	1.57
	8	5 200	3.97 (10^{-8})	1.88
Trinidad	8	3 500	1.06 (10^{-7})	2.28
	8	4 500	9.07 (10^{-8})	2.43
	8	5 500	8.32 (10^{-8})	2.59
Egypt	8	9 000	2.65 (10^{-7})	2.25
	8	11 000	1.98 (10^{-7})	2.21
	8	14 150	1.64 (10^{-7})	2.36
Angola	9	7 050	350	--
	9	11 500	350	--
	9	14 150	350	--
India	9	8 500	150	--
	9	10 500	150	--
	9	14 500	150	--

Continued on Next Page

TABLE A.4 (con't.)

Supply Region	Equation	Ultimate Potential (MMb)	A (FR_{to})	B
Malaysia	8	10 000	1.25 (10^{-7})	3.56
	8	11 500	1.08 (10^{-7})	3.44
	8	19 820	7.93 (10^{-8})	3.51
Australia	9	7 520	100	--
	9	9 520	100	--
	9	14 520	100	--
Other Middle East	8	19 820	1.22 (10^{-7})	0.80
	8	28 000	2.87 (10^{-8})	0.21
	8	28 000	2.87 (10^{-8})	0.21
North Sea	9	30 500	400	--
	9	38 300	400	--
	9	55 500	400	--
Western Europe	8	6 000	-6.74 (10^{-9})	-0.90
	8	7 000	3.06 (10^{-8})	1.73
	8	145 000	1.35 (10^{-8})	1.92

SOURCE: Canadian Energy Research Institute.

NOTE: For those regions where equation (8) is utilized, the parameter in column 3 refers to A. Conversely, if equation (9) is the specification used, column 3 refers to the initial finding rate estimated.

production for a number of years because of infrastructure requirements or other constraints. Conversely, in Canada and the U.S., new discoveries are generally in production that same year and reach peak production very rapidly; and

(ii) the rate of decline which, as noted above, differs considerably by region and field. In the U.S., for example, production generally declines quite rapidly in the early years of a producing well's life before stabilizing at a much lower rate. In the more prolific fields found in the Middle East, very high production rates can be sustained for prolonged periods of time without significant decline.

This process can be expressed in mathematical terms as:

$$PCAP_t = PROD_{t_o} * e^{-at} + \sum_{t_p=t_o+1}^{t} RA_{t_p} * PROF_{t_p-t_o} \qquad (10)$$

where:

$PCAP_t$ = regions' total productive capacity in year t

$PROD_{t_o}$ = an estimate of the productive capacity in the year prior to the beginning of the forecast

a = $PROD_t/RES_t$ = the rate of decline in existing fields

RA = projected reserves additions in year t

$PROF_{t_p-t_o}$ = production profile from new reserves additions in year (t_p-t_o) after discovery

Table A.5 provides the various production profiles that are used within the WOSM along with a listing of the supply regions which utilize each profile. It is important to note that nonconventional crude oil resources were not considered outside of Canada. Within Canada, however, the potential for adding oil sands capacity and for developing structures in the Eastern offshore and Beaufort Sea regions was explicitly incorporated using supply data employed in two recent CERI studies.[9]

TABLE A.5

PRODUCTION PROFILES EMPLOYED IN THE WOSM

Years After Discovery	1	2	3	4	5	6
1	0.07	0.10	0.04	0.08	0.04	0.02
2	0.08	0.09	0.06	0.08	0.07	0.04
3	0.08	0.08	0.06	0.08	0.12	0.06
4	0.08	0.07	0.06	0.08	0.10	0.07
5	0.07	0.07	0.06	0.07	0.09	0.08
6	0.06	0.06	0.06	0.07	0.09	0.08
7	0.06	0.06	0.05	0.06	0.07	0.08
8	0.05	0.06	0.05	0.06	0.07	0.07
9	0.05	0.05	0.05	0.06	0.06	0.06
10	0.04	0.05	0.05	0.05	0.05	0.06
11	0.04	0.04	0.05	0.05	0.05	0.05
12	0.03	0.04	0.04	0.05	0.04	0.05
13	0.03	0.04	0.04	0.04	0.04	0.04
14	0.03	0.03	0.04	0.04	0.03	0.04
15	0.02	0.03	0.04	0.03	0.03	0.03
16	0.02	0.03	0.04	0.03	0.03	0.03
17	0.02	0.02	0.04	0.03	0.02	0.03
18	0.02	0.02	0.04	0.02	0.02	0.02
19	0.02	0.02	0.04	0.02	0.02	0.02
20	0.02	0.02	0.04	0.02	0.02	0.02

SOURCE: Canadian Energy Research Institute.

LEGEND:
1. Applies to Canada, Egypt, Peru and Trinidad.
2. Applies to the U.S.
3. Applies to Malaysia, Argentina, Brazil, Other Middle East and Angola.
4. Applies to Western Europe, Australia, India and Colombia.
5. Applies to North Sea.
6. Applies to Canadian Frontier Regions.

NOTE: The production profile represents the fraction of reserves produced in the years after discovery.

A critical component of the world crude oil supply/demand balance is the level of natural gas liquids (NGLs) production. If one looks at total world crude oil production compared with demand, a supply shortfall of about 4.5 MMb/d is revealed. This shortfall is largely due to the inclusion of NGLs in the petroleum product consumption statistics. Since the balancing of supply and demand play a critical role in determining prices in the integrated world oil model, the production of NGLs must be accounted for. As it is beyond the scope of this analysis to determine NGL production endogenously, their levels are specified exogenously. Initial NGL production levels by region are taken from available statistical information and assumed to either grow or decline according to an annual rate which is exogenously specified by the user. This data is provided in Table A.6.

Refinery gain, which is an increase in volume obtained when processing crude oil into lighter products, also contributes to the observed statistical imbalance. Here, the International Energy Agency's (IEA) assumption of 1.1 MMb/d was embedded in the WOSM.

Finally, it was necessary to assume future levels of crude oil production in the CPE's, primarily because of the futility of trying to forecast the planning process in these countries. The production levels assumed for these countries in the reference case projections are presented in Table A.7. It should be noted that these levels were predicated on the assumption that net CPE exports would virtually disappear by the year 2000.[10] Net CPE exports over the forecast horizon are also shown in Table A.7.

A.3.4 The Cost Submodel

The current instability in the world oil market and the dramatic fall in oil prices during 1986 have stimulated great interest in the lower limit for world oil prices (often referred to as the "competitive floor") and its sustainability over time. Presumably, such a situation might develop if OPEC cooperation were to disintegrate and individual member nations began producing at capacity. Alternatively, prices could fall dramatically, but not quite to the competitive floor, if one or more OPEC nations were to completely disregard their production quotas, not an implausible scenario given the cash flow needs of a number of member countries.

The cost submodel of the WOSM provides the analytical framework with the ability to consistently analyze this problem through two features:

TABLE A.6

ASSUMED LEVELS OF NATURAL GAS LIQUIDS PRODUCTION (Mb/d)

Year	Argentina	Australia	Brazil	Canada	Egypt	Mexico	Malaysia
1988	31.6	93.8	21.6	357.0	31.2	343.3	46.0
1989	31.2	91.5	22.0	350.6	32.4	352.0	46.0
1990	30.8	89.3	22.4	344.3	33.7	360.9	46.0
1991	30.4	87.1	22.9	338.1	35.0	370.1	46.0
1992	30.0	85.0	23.3	332.0	33.3	379.4	46.0
1993	29.6	82.9	23.7	326.0	31.6	389.0	46.0
1994	29.2	80.9	24.2	320.2	30.1	398.9	46.0
1995	28.9	78.9	24.6	314.4	28.6	409.0	46.0
1996	28.5	77.0	25.1	308.7	27.1	419.3	46.0
1997	28.1	75.1	25.5	303.2	25.8	429.9	46.0
1998	27.7	73.2	25.1	297.7	24.5	440.8	46.0
1999	27.4	71.4	24.7	292.4	23.3	451.9	46.0
2000	27.0	69.7	24.3	287.1	22.1	463.4	46.0
2001	26.7	68.0	23.9	281.9	21.0	460.8	46.0
2002	26.3	66.3	23.5	276.9	20.0	458.2	46.0
2003	26.0	64.7	23.1	271.9	19.0	455.6	46.0
2004	25.6	63.1	22.7	267.0	18.0	453.1	46.0
2005	25.3	61.6	22.4	262.2	17.1	450.5	46.0

Year	North Sea	India	Other Middle East	United States	Western Europe	Total Non-OPEC	Total OPEC
1988	249.7	6.0	43.7	1610.7	37.2	2872.0	1706.2
1989	255.2	6.0	44.8	1573.7	38.8	2844.5	1767.8
1990	260.9	6.0	45.9	1537.6	40.5	2818.4	1831.6
1991	266.6	6.0	47.0	1502.3	42.3	2793.8	1897.8
1992	272.5	6.0	48.2	1467.8	44.1	2767.6	1966.3
1993	278.5	6.0	49.4	1434.1	41.3	2738.3	2037.3
1994	262.1	6.0	50.6	1401.2	38.7	2688.0	2110.9
1995	246.6	6.0	51.9	1369.0	36.3	2640.1	2187.1
1996	232.1	6.0	53.2	1337.6	34.0	2594.5	2266.1
1997	218.4	6.0	54.5	1306.9	31.8	2551.2	2347.9
1998	205.5	6.0	55.9	1276.9	29.8	2509.2	2432.7
1999	193.4	6.0	55.2	1247.6	27.9	2467.2	2520.5
2000	182.0	6.0	54.6	1218.9	26.2	2427.2	2611.6
2001	171.2	6.0	53.9	1190.9	24.5	2374.9	2705.2
2002	161.1	6.0	53.3	1163.6	23.0	2324.1	2803.6
2003	151.6	6.0	52.6	1136.9	21.5	2274.9	2904.8
2004	142.7	6.0	52.0	1110.8	20.2	2227.2	3009.7
2005	134.3	6.0	51.4	1085.3	18.9	2180.9	3118.4

SOURCE: Canadian Energy Research Institute.

TABLE A.7

ASSUMED LEVELS OF CPE PRODUCTION
(Mb/d)

Year	Russia	Eastern Europe	China	Total	Net Exports
1988	12 600	440	2 770	15 810	2.18
1989	12 650	430	2 880	15 960	2.15
1990	12 750	420	3 000	16 170	2.18
1991	12 650	410	3 100	16 160	1.98
1992	12 610	400	3 200	16 210	1.83
1993	12 470	390	3 300	16 160	1.58
1994	12 510	380	3 300	16 190	1.38
1995	12 560	370	3 300	16 230	1.19
1996	12 620	360	3 300	16 280	1.00
1997	12 660	350	3 300	16 310	0.80
1998	12 710	340	3 300	16 350	0.60
1999	12 710	330	3 300	16 340	0.35
2000	12 710	320	3 300	16 330	0.10
2001	12 760	311	3 313	16 384	0.10
2002	12 780	312	3 316	16 408	0.10
2003	12 780	312	3 316	16 408	0.10
2004	12 780	312	3 316	16 408	0.10
2005	12 780	312	3 316	16 408	0.10

SOURCE: Canadian Energy Research Institute.

(i) an algorithm to estimate the distribution of operating costs across existing fields worldwide; and

(ii) an algorithm to estimate full-cycle supply costs in each supply region.

Obviously, without making some major simplifying assumptions, the estimation of operating and supply costs by country is a nearly impossible task. The approach employed in the WOSM is to assume that annual operating costs are some fixed proportion of installed field capital. Installed field capital is defined as the cost of development drilling and field equipment. This was accomplished for onshore fields by assuming that:

(i) drilling and completion costs are a function of average well depth and geographical location; and

(ii) production, treatment and pumping equipment are a function of field parameters such as average well depth, average flowrate and geographical location.

Cost equations were estimated for onshore and offshore drilling costs using U.S. cost data. Estimates of the typical cost of installing field and pumping equipment for a representative onshore producing well in North America at various flowrates were prepared by an outside consultant.

A similar approach was applied to estimate drilling and equipment costs for offshore fields. Detailed and reliable data on North Sea development and equipment costs is available in a report compiled by Wood, Mackenzie and Co.[11] Four cost categories are identified--development drilling costs, platform costs, installation costs, and platform equipment costs. While acknowledging that development and operating costs depend heavily on water depth and distance to shore (among other factors), cost equations were estimated only as a function of field capacity and geographical location, owing to the lack of additional data.

Average annual operating costs for each of the fields contained in the data base are calculated by assuming they are a fixed proportion (15 percent) of installed field capital as estimated using the cost equations. A per barrel estimate of average field operating costs is then calculated as the yearly operating costs divided by annual field production. With this information, operating cost curves are constructed for each supply region having sufficient data. These operating cost curves describe the distribution of operating costs across each region's existing oil production as a function of price. Given the world oil price, the amount of oil production that might be shut-in in any region can be estimated as the intersection of the world oil price with the operating cost curve.

The various components of the world oil supply model, when combined with the cost submodel, provide a consistent basis for estimating full-cycle supply costs in each supply region. The simplifying assumptions and steps required to make these calculations are as follows:

(i) a representative field size in each region is calculated as the average of existing field sizes;

(ii) this representative field is assumed to be produced at the region's historical decline rate;

(iii) the number of producing wells is calculated as the total field production (calculated from the assumed decline rate) divided by the region's weighted average flow rate per well;

(iv) the depth of these wells is calculated as the average of existing well depths; and

(v) the total amount of drilling required to find and develop the representative field is calculated as the field size divided by the regional finding rate.

This is sufficient information to estimate the capital costs of finding and developing a representative field as well as the average per barrel operating costs. The full-cycle supply cost is calculated as the price required to just make the field economic, by multiplying the required capital investment per daily barrel by the sum of the minimum acceptable rate of return and the historical decline rate, and adding operating costs.[12] This equation thus has the following form

$$FSC = (K/Q)*(a + i) + OC \tag{11}$$

where:

FSC = full-cycle supply cost in \$1988 U.S. per barrel

K = required capital investment

Q = initial yearly production rate

OC = average per-unit operating costs

a = historical decline rate

i = minimum acceptable rate of return (before tax)

The minimum acceptable rate of return assumed in these calculations was 16 percent, allowing 8 percent for the financial opportunity cost and 8 percent for the risk premium on diversified oil operations.[13] Table 3.6 in Section 3.5 of the WOMS presents regional marginal supply costs estimated as of 1987.

A.4 Summary and the Integrated World Oil Market Model

Chapters 2 and 3 of the WOMS provide a conceptual overview of the World Oil Demand and Supply models. Sections A.1 and A.2 above have provided somewhat more detail about the actual structure and key assumptions underlying these components. To summarize, projections of total world oil demand are built up from regionally based forecasts, disaggregated by refined product. The key data inputs required to implement the demand model include world oil prices and GDP growth rates for the seven regions contained in the model. Other parameters, such as price and income elasticities, may be adjusted as well to simulate the response of product demand to changes in price and economic growth in each region.

Projections of world oil production are also built up from the regional level. However, it is necessary that this component embody the existing market structure of oil producing nations. Each country is assumed to be either a member of the competitive fringe or of OPEC. The competitive fringe is comprised of production from non-CPE countries and CPE net exports. Supply projections (based on the methodology discussed above) are generated for those regions in the competitive fringe, as it is reasonable to assume that these countries are price-takers--that is, that their drilling and production programs are predicated on prevailing and expected prices and that they have little power to set prices. The only exogenous variables required to generate projections of non-OPEC crude oil production are world oil prices and interest rates, the two primary drivers of drilling activity. However, in building up a composite of total non-OPEC oil supplies, a regional exogenous NGL production path must be provided (see Section A.3).

Each of these components of the World Oil Market model can be implemented on a stand-alone basis simply by

specifying the required data inputs as described above and in Chapters 2 and 3 of the WOMS. While this in itself serves a valuable role in examining the potential evolution of world oil demand or supply, the primary motivation in their construction was to create a system capable of generating consistent projections of one of two critical variables:

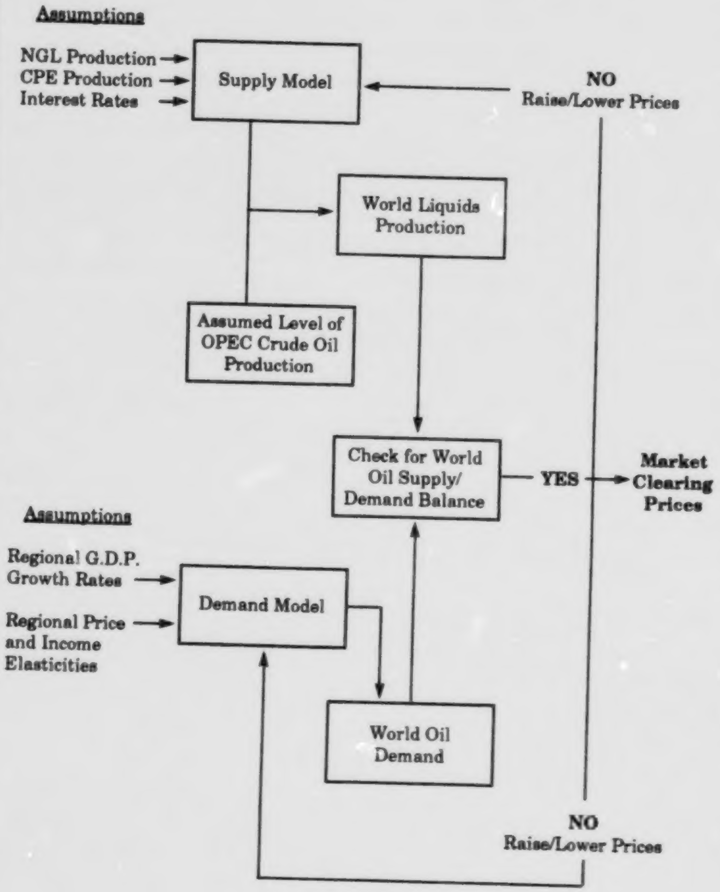
- world oil prices, defined to represent West Texas Intermediate (WTI) prices at Cushing, Oklahoma; or
- OPEC production levels, which represent total crude oil production of the Organization.

A.4.1 Market Clearing Price Projection Mode

The perspective adopted in this mode is that OPEC sets and adheres to a quota for total cartel production, and then allows competitive market forces to determine oil prices. This is the strategy that has been adopted by OPEC since early 1988, when the cartel abandoned (in practice) its schedule of fixed prices for crude oil exports. Figure A.3 provides a simple flow diagram of this process. Obviously, the most crucial assumption required here is the hypothesized level of OPEC production over the forecast horizon. As noted above, it is feasible to develop a model to forecast crude oil production in the competitive fringe. However, any similar attempt to forecast cartel production is fraught with complexities, as future output levels will be highly dependent on a combination of strategic, political and sociological factors which are virtually impossible to capture in an economic framework. **In our view, the high degree of uncertainty regarding future cartel production levels is best resolved by incorporating within the model framework the flexibility to deal with an array of potential scenarios.**

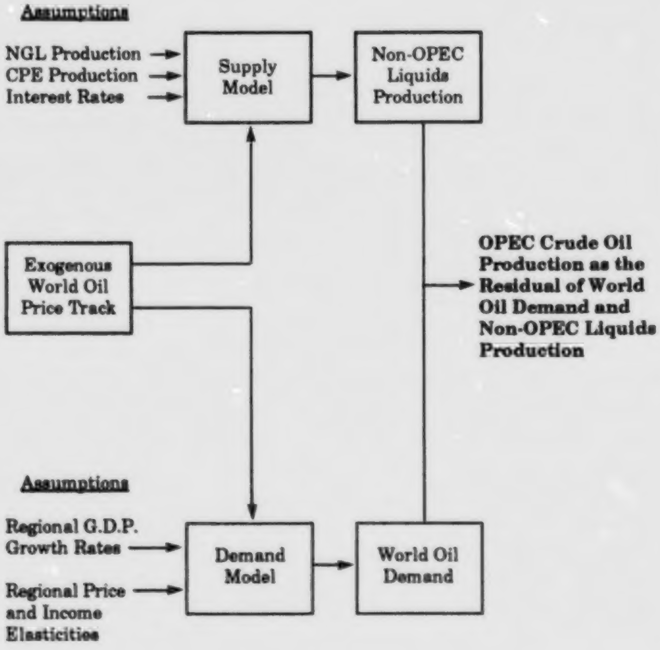
Once OPEC production levels are set over the forecast horizon, future prices are determined using a recursive solution routine. Given an initial price level, total world oil demand and supply are calculated, and the resulting supply/demand balance is checked against a convergence criteria. If excess demand (supply) is detected, the price is raised (lowered) according to the degree of imbalance. This procedure is repeated until convergence between supply and demand is reached. The output of the simulation are annual, average "market clearing" prices and volumes. **In Version 3.1 of the WOMM, the solution routine has been enhanced to significantly reduce the number of iterations required to reach a solution.** By estimating a per barrel cost of excess supply or demand based upon prior

Figure A.3
The Price Projection Mode of the World Oil Market Model


Assumptions
NGL Production
CPE Production
Interest Rates
Supply Model
NO
Raise/Lower Prices
World Liquids Production
Assumed Level of OPEC Crude Oil Production
Check for World Oil Supply/ Demand Balance
YES
Market Clearing Prices
Assumptions
Regional G.D.P. Growth Rates
Regional Price and Income Elasticities
Demand Model
World Oil Demand
NO
Raise/Lower Prices

SOURCE: CERI.

Figure A.4
The OPEC Production Mode of the
World Oil Market Model


Assumptions
NGL Production
CPE Production
Interest Rates
Supply Model
Non-OPEC Liquids Production
Exogenous World Oil Price Track
OPEC Crude Oil Production as the Residual of World Oil Demand and Non-OPEC Liquids Production
Assumptions
Regional G.D.P. Growth Rates
Regional Price and Income Elasticities
Demand Model
World Oil Demand

SOURCE: CERI.

solutions, the WOMM will now solve for the market clearing price in a maximum of four iterations.

A.4.2 OPEC Production Mode

Alternatively, OPEC members could potentially set a desired price level and subsequently take whatever share of the market is left to them at those fixed prices. Realistically, this is a much more difficult strategy to follow, given the wide range of crude types produced in the member countries and the need to price each according to its particular qualities. As Figure A.4 illustrates, this simulation mode is very similar to the price projection mode, except that instead of specifying OPEC production levels, an exogenous world oil price track must be provided over the forecast horizon. In this particular case, there is no need for a recursive type of solution procedure, since OPEC production is calculated as the residual of world oil demand and non-OPEC oil production.

We do not make any attempt to allocate cartel production amongst the various OPEC member countries. Indeed, we see the primary use of this simulation mode as a quick check on the consistency of any "ad hoc" type of oil price forecast. Glaring inconsistencies in such a forecast, such as unacceptably low levels of OPEC production, and their underlying causes can thus be quickly identified.

Footnotes

[1] For an introduction to the Koyck-transformed partial adjustment demand equation, see the description in G. S. Maddala, *Econometrics* (1977).

[2] See, for example, Carol A. Dahl, "Do Gasoline Demand Elasticities Vary?", *Land Economics,* 58 (3), August 1982; U.S. Department of Energy, *Price Elasticity of Demand for Motor Gasoline and Other Petroleum Products*, (Washington, D.C.: 1982); A. B. Askin and J. Kraft, eds., *Econometric Dimensions of Energy Supply and Demand*, (Lexington, Mass.: 1976); Energy Modeling Forum, *Aggregate Elasticity of Demand* (Stanford, Cal.: 1980); J. Kraft and M. Rodekohr, "Regional Demand for Gasoline: A Temporal Cross-Sectional Specification," *Journal of Regional Science*, 18 (1), January 1978; Robert Archibald and Robert Gillingham, "An Analysis of the Short-Run Consumer Demand for Gasoline," *Review of Economics and Statistics,* November 1980; C. Garbacz, "Residential Fuel Oil Demand," *Applied Economics*, August 1985; and N. D. Uri and S. Hassanein, "Gasoline and Fuel Oil Demand," *Energy Economics*, April 1985.

[3] Obtained from the U.S. Department of Energy publication, *International Energy Annual.*

[4] Some examples of Canadian based models include, Brian L. Scarfe and Edwin W. Rilkoff, *Financing Oil and Gas Exploration and Development Activity*, Discussion Paper No. 274, (Ottawa: Economic Council of Canada, December 1984); S. Madduri and J. N. Tanner, "A Petroleum Activity Model," Alberta Energy and Natural Resources Working Paper (Edmonton: September 1983); Peter C. Bing and John Gillies," A Model of Exploration Drilling Activity," paper presented to the Ninth International Conference of the International Association of Energy Economists in Calgary, Alberta, July 1987; and Abba Bhargava, "Saskatchewan Disaggregated Drilling Model," paper presented to Saskatchewan Department of Energy and Mines, 1987.

[5] Two excellent reviews of these different types of methodologies are contained in Morris A. Adleman, J. C. Houghton, G. Kaufman, and M. Zimmerman, *Estimation of Resources and Reserves*, report prepared for the Electric Power Research Institute (Palo Alto: 1982); and Mathtech Incorporated, *Comparative State-of-the-Art Assessment of Oil Supply Modelling,* report prepared for the Electric Power Research Institute (Palo Alto: 1978).

[6] M. King Hubbard, "Degree of Advancement of Petroleum Exploration in United States," *The American Association of Petroleum Geologists Bulletin*, vol. 51/11 (November 1967).

[7] Hubbard also employed a logistic function. We have modified this model so that cumulative discoveries become a function of cumulative drilling effort rather than time.

[8] These sources include: C. D. Masters, D. H. Roots, and W. D. Dietzman, "Distribution and Quantitative Assessment of World Crude Oil Reserves and Resources," Eleventh World Petroleum Congress, Volume 2 (1983) pp. 229-237; U.S. Department of Energy,

Energy Information Administration, *Foreign Energy Supply Assessment Series*, Various Publications; Geological Survey of Canada, *Conventional Oil Resources of Western Canada*, paper 87-26 (Ottawa: Minister of Supply and Services, 1988); U.S. Department of the Interior, Geological Survey Circular 860, *Estimates of Undiscovered Recoverable Conventional Resources of Oil and Gas in the United States*, (Washington; 1981).

[9] Supply costs and development profiles for Canadian frontier reserves were based on assumptions employed in two CERI studies, K. Morgan MacRae, *An Assessment of the Potential for Coal-Derived Syncrudes in Canada*, Study No. 27 (Calgary: Canadian Energy Research Institute, June 1988); and J. T. Tanner and A. E. Reinsch, *Canadian Crude Oil Supply/Demand Balances*, Study No. 31 (Calgary: Canadian Energy Research Institute, August 1989).

[10] These assumptions for refinery gain and net CPE exports are consistent with those employed by the International Energy Agency. See International Energy Agency, "Long-term Energy Outlook," Mimeo (Paris: 1988).

[11] Wood, MacKenzie and Co., "Section 2 of the North Sea Service," (Edinburgh: June 1976).

[12] See M. A. Adleman, "The Competitive Floor to World Oil Prices," *The Energy Journal*, vol. 7, no. 4 (October 1986), p. 13, for a simple derivation of this model.

[13] Ibid., pp. 13-14.

APPENDIX B

REFERENCE CASE G.D.P. FORECAST

Appendix B

REFERENCE CASE G.D.P. FORECASTS

As described in Chapter 2, the CERI World Oil Market model requires as input data an exogenous forecast of economic growth in each of the seven major oil-consuming regions. The regional GDP forecasts used for the reference and test cases of the model are illustrated in Table D.1. Forecasts for the years up to 2000 were sourced from data provided by the Energy Information Administration, *Annual Energy Outlook 1989* and the *International Energy Outlook 1989*. These estimates were modified to account for assumed business cycle adjustments. Estimates for OPEC and the CPEs were calculated by CERI analysts. Projections beyond 2000 were calculated on the basis of long-term average growth rates.

TABLE B.1

FORECAST OF ECONOMIC GROWTH BY REGION
REFERENCE CASE
1988-2000
(% per year)

Year	Canada	U.S.A.	Western Europe	Pacific OECD	Less Developed Countries	OPEC	Centrally Planned Economies
1988	5.0	4.4	3.5	5.9	2.9	1.4	3.1
1989	3.2	3.2	2.7	4.0	2.9	1.6	2.9
1990	3.2	3.1	2.7	3.9	3.1	2.8	3.2
1991	3.1	3.0	2.6	3.7	3.3	3.1	3.3
1992	3.1	2.9	2.6	3.6	3.4	3.6	3.4
1993	3.1	2.7	2.5	3.4	3.6	3.4	3.2
1994	3.0	2.6	2.5	3.2	3.8	3.4	3.7
1995	3.0	2.5	2.4	3.1	4.0	3.6	3.8
1996	3.0	2.4	2.4	2.9	4.2	3.5	3.9
1997	2.9	2.3	2.3	2.8	4.4	3.5	3.5
1998	2.9	2.2	2.3	2.6	4.5	3.5	3.5
1999	2.9	2.0	2.2	2.5	4.7	3.5	3.5
2000	2.9	1.9	2.2	2.3	4.9	3.5	3.5
2001	2.9	2.0	2.2	2.4	4.8	3.5	3.5
2002	2.9	2.8	3.0	3.8	3.8	3.5	3.5
2003	2.9	2.6	2.8	3.4	4.0	3.5	3.5
2004	2.9	2.4	2.6	3.1	4.3	3.5	3.5
2005	2.9	2.2	2.4	2.7	4.5	3.5	3.5

SOURCES: (1) United States Department of Energy, Energy Information Administration, *Annual Energy Outlook 1989*; (2) United States Department of Energy, Energy Information Administration, *International Energy Outlook 1989*; and (3) Canadian Energy Research Institute.

APPENDIX C

REFERENCE CASE REGIONAL OIL PRODUCTS DEMAND

TABLE C.1

CANADA
REGIONAL OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	600	473	119	428	1,620
1991	608	469	116	439	1,632
1992	616	466	114	449	1,646
1993	624	464	112	459	1,659
1994	633	463	110	469	1,675
1995	642	462	108	479	1,691
1996	651	460	106	488	1,705
1997	660	458	104	496	1,718
1998	669	457	102	504	1,733
1999	678	455	100	511	1,744
2000	687	453	98	518	1,755
2001	697	453	97	526	1,772
2002	706	452	96	534	1,788
2003	715	451	95	542	1,802
2004	724	449	94	550	1,816
2005	733	447	93	558	1,830

SOURCE: Canadian Energy Research Institute.

TABLE C.2

UNITED STATES
REGIONAL OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	7,996	4,875	1,786	3,769	18,425
1991	8,186	4,885	1,759	3,822	18,651
1992	8,366	4,889	1,733	3,871	18,859
1993	8,535	4,888	1,707	3,916	19,045
1994	8,697	4,888	1,685	3,959	19,229
1995	8,851	4,886	1,664	3,999	19,401
1996	8,989	4,871	1,636	4,033	19,530
1997	9,114	4,849	1,606	4,062	19,631
1998	9,236	4,832	1,582	4,090	19,741
1999	9,343	4,805	1,553	4,112	19,813
2000	9,436	4,771	1,522	4,129	19,857
2001	9,536	4,753	1,502	4,150	19,941
2002	9,637	4,730	1,477	4,170	20,015
2003	9,739	4,707	1,452	4,190	20,088
2004	9,837	4,680	1,425	4,208	20,151
2005	9,930	4,650	1,398	4,224	20,202

SOURCE: Canadian Energy Research Institute.

TABLE C.3

WESTERN EUROPE
REGIONAL OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	3,092	5,451	2,738	2,166	13,447
1991	3,194	5,470	2,681	2,152	13,497
1992	3,287	5,481	2,631	2,144	13,543
1993	3,372	5,485	2,585	2,140	13,583
1994	3,452	5,489	2,547	2,140	13,628
1995	3,527	5,491	2,512	2,143	13,673
1996	3,595	5,480	2,468	2,147	13,690
1997	3,657	5,462	2,421	2,152	13,692
1998	3,717	5,450	2,383	2,159	13,709
1999	3,772	5,428	2,339	2,165	13,704
2000	3,822	5,399	2,292	2,171	13,684
2001	3,874	5,387	2,262	2,180	13,703
2002	3,927	5,371	2,225	2,190	13,713
2003	3,981	5,355	2,187	2,201	13,724
2004	4,034	5,335	2,147	2,212	13,727
2005	4,085	5,312	2,107	2,222	13,727

SOURCE: Canadian Energy Research Institute.

TABLE C.4

PACIFIC OECD
REGIONAL OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	1,097	1,761	864	1,850	5,573
1991	1,127	1,765	838	1,895	5,625
1992	1,156	1,767	819	1,940	5,682
1993	1,184	1,768	804	1,984	5,740
1994	1,212	1,770	793	2,028	5,801
1995	1,239	1,771	784	2,071	5,865
1996	1,264	1,767	772	2,111	5,914
1997	1,287	1,760	759	2,148	5,955
1998	1,310	1,755	749	2,184	5,998
1999	1,331	1,746	737	2,217	6,031
2000	1,350	1,734	724	2,247	6,054
2001	1,370	1,728	716	2,279	6,093
2002	1,391	1,721	706	2,313	6,132
2003	1,413	1,714	696	2,348	6,171
2004	1,435	1,706	685	2,383	6,208
2005	1,456	1,697	674	2,417	6,243

SOURCE: Canadian Energy Research Institute.

TABLE C.5

LESS DEVELOPED COUNTRIES REGIONAL OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	1,684	3,516	2,434	2,183	9,817
1991	1,698	3,548	2,459	2,180	9,885
1992	1,714	3,590	2,488	2,181	9,972
1993	1,732	3,641	2,521	2,185	10,080
1994	1,752	3,704	2,561	2,193	10,211
1995	1,774	3,778	2,607	2,204	10,364
1996	1,797	3,857	2,653	2,217	10,524
1997	1,821	3,943	2,702	2,232	10,698
1998	1,848	4,042	2,760	2,251	10,901
1999	1,876	4,147	2,819	2,271	11,114
2000	1,906	4,259	2,881	2,293	11,338
2001	1,940	4,390	2,957	2,320	11,607
2002	1,973	4,517	3,026	2,346	11,862
2003	2,006	4,645	3,094	2,372	12,117
2004	2,039	4,776	3,161	2,398	12,375
2005	2,073	4,912	3,230	2,425	12,640

SOURCE: Canadian Energy Research Institute.

TABLE C.6

OPEC
REGIONAL OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	926	1,664	876	678	4,145
1991	951	1,708	892	701	4,253
1992	978	1,757	911	725	4,371
1993	1,007	1,810	932	750	4,499
1994	1,038	1,868	956	776	4,637
1995	1,071	1,931	982	803	4,787
1996	1,106	1,996	1,008	831	4,941
1997	1,143	2,064	1,035	860	5,101
1998	1,182	2,136	1,064	890	5,273
1999	1,222	2,210	1,093	921	5,446
2000	1,263	2,286	1,122	953	5,625
2001	1,307	2,368	1,155	986	5,816
2002	1,353	2,452	1,188	1,020	6,012
2003	1,401	2,539	1,222	1,055	6,216
2004	1,451	2,628	1,256	1,091	6,426
2005	1,503	2,720	1,290	1,128	6,641

SOURCE: Canadian Energy Research Institute.

TABLE C.7

CENTRALLY PLANNED ECONOMIES
REGIONAL OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	2,673	4,062	4,061	3,193	13,990
1991	2,716	4,110	4,109	3,244	14,179
1992	2,761	4,161	4,160	3,298	14,379
1993	2,806	4,212	4,211	3,352	14,580
1994	2,856	4,269	4,268	3,412	14,806
1995	2,909	4,329	4,328	3,475	15,041
1996	2,964	4,391	4,390	3,541	15,285
1997	3,017	4,450	4,449	3,604	15,520
1998	3,071	4,509	4,508	3,668	15,756
1999	3,124	4,567	4,566	3,731	15,989
2000	3,178	4,626	4,625	3,796	16,225
2001	3,234	4,687	4,686	3,862	16,468
2002	3,291	4,749	4,748	3,930	16,718
2003	3,349	4,812	4,811	4,000	16,972
2004	3,407	4,874	4,873	4,069	17,224
2005	3,466	4,937	4,936	4,139	17,478

SOURCE: Canadian Energy Research Institute.

TABLE C.8

WORLD OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	18,068	21,802	12,878	14,267	67,017
1991	18,480	21,955	12,854	14,433	67,723
1992	18,878	22,111	12,856	14,608	68,452
1993	19,260	22,268	12,872	14,786	69,184
1994	19,640	22,451	12,920	14,977	69,986
1995	20,013	22,648	12,985	15,174	70,823
1996	20,366	22,822	13,033	15,368	71,589
1997	20,699	22,986	13,076	15,554	72,314
1998	21,033	23,181	13,148	15,746	73,110
1999	21,346	23,358	13,207	15,928	73,841
2000	21,642	23,528	13,264	16,107	74,539
2001	21,958	23,766	13,375	16,303	75,400
2002	22,278	23,992	13,466	16,503	76,240
2003	22,604	24,223	13,557	16,708	77,092
2004	22,927	24,448	13,641	16,911	77,927
2005	23,246	24,675	13,728	17,113	78,761

SOURCE: Canadian Energy Research Institute.

TABLE C.9

WORLD (EXCLUDING CPEs) OIL PRODUCTS DEMAND
1990-2005
(Mb/d)

Year	Gasoline	Middle Distillate	Heavy Fuel Oil	Other	Total Crude Oil
1990	15,395	17,740	8,817	11,074	53,027
1991	15,764	17,845	8,745	11,189	53,543
1992	16,117	17,950	8,696	11,310	54,073
1993	16,454	18,056	8,661	11,434	54,604
1994	16,784	18,182	8,652	11,565	55,181
1995	17,104	18,319	8,657	11,699	55,782
1996	17,402	18,431	8,643	11,827	56,304
1997	17,682	18,536	8,627	11,950	56,795
1998	17,962	18,672	8,640	12,078	57,354
1999	18,222	18,791	8,641	12,197	57,852
2000	18,464	18,902	8,639	12,311	58,313
2001	18,724	19,079	8,689	12,441	58,932
2002	18,987	19,243	8,718	12,573	59,522
2003	19,255	19,411	8,746	12,708	60,119
2004	19,520	19,574	8,768	12,842	60,703
2005	19,780	19,738	8,792	12,974	61,283

SOURCE: Canadian Energy Research Institute.

APPENDIX D

REFERENCE CASE REGIONAL SUPPLY PROJECTIONS

TABLE D.1

ANGOLA/CONGO/CAMEROON DETAILED REGIONAL SUPPLY FORECAST 1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	774.5	307	238.1	799.7	0.0	799.7
1991	796.5	291	231.9	804.1	0.0	804.1
1992	807.5	274	221.4	807.5	0.0	807.5
1993	819.0	257	210.3	809.4	0.0	809.4
1994	827.1	239	197.9	809.5	0.0	809.5
1995	836.5	222	185.4	807.6	0.0	807.6
1996	853.8	204	174.1	804.1	0.0	804.1
1997	870.2	186	162.2	798.7	0.0	798.7
1998	878.9	169	148.9	791.4	0.0	791.4
1999	897.3	153	137.2	782.2	0.0	782.2
2000	916.2	137	125.7	771.9	0.0	771.9
2001	919.1	122	112.5	760.3	0.0	760.3
2002	937.6	109	101.9	747.7	0.0	747.7
2003	953.4	96	91.6	734.3	0.0	734.3
2004	971.8	84	82.1	720.0	0.0	720.0
2005	989.7	74	73.2	705.1	0.0	705.1

SOURCE: Canadian Energy Research Institute.

TABLE D.2

ARGENTINA
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	4,071.8	24	97.9	458.0	30.8	488.8
1991	4,292.7	23	99.6	450.0	30.4	480.4
1992	4,418.1	22	98.7	444.5	30.0	474.5
1993	4,552.2	21	97.5	440.6	29.6	470.2
1994	4,660.5	21	95.6	437.1	29.2	466.4
1995	4,782.3	20	93.6	434.1	28.9	463.0
1996	4,977.3	19	92.7	431.1	28.5	459.6
1997	5,166.0	18	91.2	428.2	28.1	456.3
1998	5,283.5	17	88.1	425.3	27.7	453.0
1999	5,493.4	16	86.3	422.2	27.4	449.6
2000	5,706.7	15	84.0	419.1	27.0	446.1
2001	5,776.3	14	79.4	415.4	26.7	442.0
2002	5,988.8	13	76.7	411.5	26.3	437.8
2003	6,178.7	12	73.4	406.9	26.0	432.9
2004	6,394.1	11	70.2	402.1	25.6	427.8
2005	6,605.6	10	66.7	396.9	25.3	422.2

SOURCE: Canadian Energy Research Institute.

TABLE D.3

AUSTRALIA/NEW ZEALAND
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	1,532.3	88	134.7	561.6	89.3	651.0
1991	1,598.4	83	132.6	550.7	87.1	637.9
1992	1,631.3	78	127.1	539.6	85.0	624.5
1993	1,665.8	73	121.0	528.0	82.9	610.9
1994	1,690.2	67	113.7	516.0	80.9	596.8
1995	1,718.5	62	106.4	503.4	78.9	582.3
1996	1,770.3	57	100.0	490.5	77.0	567.5
1997	1,819.4	51	93.1	477.3	75.1	552.3
1998	1,845.6	46	84.8	463.4	73.2	536.7
1999	1,901.1	41	77.8	449.2	71.4	520.7
2000	1,957.6	36	70.8	434.7	69.7	504.4
2001	1,966.5	32	62.5	419.7	68.0	487.6
2002	2,021.8	28	56.0	404.4	66.3	470.7
2003	2,069.4	24	49.7	389.0	64.7	453.7
2004	2,124.7	21	44.0	373.6	63.1	436.7
2005	2,178.4	18	38.6	358.2	61.6	419.8

SOURCE: Canadian Energy Research Institute.

TABLE D.4

BRAZIL
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	4,365.5	88	382.0	630.1	22.4	652.5
1991	4,401.7	83	365.7	649.8	22.9	672.7
1992	4,419.8	78	343.3	667.7	23.3	691.0
1993	4,438.7	72	317.8	682.9	23.7	706.6
1994	4,452.1	65	290.0	694.6	24.2	718.8
1995	4,467.6	59	261.5	702.4	24.6	727.0
1996	4,496.0	52	233.9	706.4	25.1	731.4
1997	4,522.9	46	207.0	706.4	25.5	731.9
1998	4,537.3	40	180.9	702.6	25.1	727.7
1999	4,567.6	34	157.4	695.3	24.7	720.0
2000	4,598.6	30	136.0	685.9	24.3	710.2
2001	4,603.5	25	116.0	674.6	23.9	698.5
2002	4,633.8	21	99.0	661.9	23.5	685.4
2003	4,659.9	18	84.0	648.1	23.1	671.2
2004	4,690.2	15	70.9	633.4	22.7	656.1
2005	4,719.7	13	59.7	618.1	22.4	640.4

SOURCE: Canadian Energy Research Institute.

TABLE D.5

CANADA
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	26,910.2	12	316.4	1,577.1	344.3	1,921.3
1991	27,805.1	11	302.4	1,540.5	338.1	1,878.6
1992	28,260.7	10	281.6	1,501.7	332.0	1,833.8
1993	28,737.2	9	259.7	1,504.1	326.0	1,830.1
1994	29,090.7	8	236.2	1,507.3	320.2	1,827.5
1995	29,495.7	7	213.0	1,505.4	314.4	1,819.8
1996	30,215.7	6	191.9	1,484.7	308.7	1,793.5
1997	30,897.9	6	170.8	1,456.1	303.2	1,759.3
1998	31,276.1	5	149.2	1,408.7	297.7	1,706.4
1999	32,042.9	4	130.7	1,404.8	292.4	1,697.1
2000	32,830.3	3	113.5	1,374.1	287.1	1,661.2
2001	32,984.5	3	96.2	1,340.7	281.9	1,622.7
2002	33,756.8	2	82.6	1,288.5	276.9	1,565.4
2003	34,427.9	2	70.4	1,241.6	271.9	1,513.5
2004	35,203.1	2	59.8	1,179.0	267.0	1,446.0
2005	35,960.2	1	50.6	1,119.2	262.2	1,381.3

SOURCE: Canadian Energy Research Institute.

TABLE D.6

COLOMBIA AND OTHER SOUTH AMERICA DETAILED REGIONAL SUPPLY FORECAST 1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	2,894.6	60	173.6	470.2	0.0	470.2
1991	2,934.0	59	171.7	483.8	0.0	483.8
1992	2,953.7	57	168.2	496.1	0.0	496.1
1993	2,974.3	55	164.3	506.9	0.0	506.9
1994	2,988.9	53	159.6	516.0	0.0	516.0
1995	3,005.8	51	154.8	523.4	0.0	523.4
1996	3,036.7	50	150.3	529.1	0.0	529.1
1997	3,066.1	47	145.5	533.9	0.0	533.9
1998	3,081.7	45	139.8	536.7	0.0	536.7
1999	3,114.8	43	134.6	537.6	0.0	537.6
2000	3,148.6	41	129.3	536.6	0.0	536.6
2001	3,153.9	39	122.7	533.3	0.0	533.3
2002	3,186.9	37	117.2	528.1	0.0	528.1
2003	3,215.4	35	111.5	520.9	0.0	520.9
2004	3,248.4	33	105.9	512.1	0.0	512.1
2005	3,280.5	31	100.3	501.9	0.0	501.9

SOURCE: Canadian Energy Research Institute.

TABLE D.7

EGYPT/TUNISIA
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	1,760.6	222	390.5	1,180.5	33.7	1,214.3
1991	1,775.6	168	297.6	1,199.9	35.0	1,235.0
1992	1,784.5	124	221.2	1,192.6	33.3	1,225.9
1993	1,793.0	90	161.8	1,165.7	31.6	1,197.4
1994	1,799.5	65	116.8	1,125.3	30.1	1,155.4
1995	1,806.7	46	83.6	1,076.5	28.6	1,105.1
1996	1,817.7	33	59.6	1,023.0	27.1	1,050.1
1997	1,828.4	23	42.2	967.4	25.8	993.2
1998	1,835.2	16	29.6	911.7	24.5	936.2
1999	1,847.3	11	20.8	857.1	23.3	880.4
2000	1,859.6	8	14.6	804.5	22.1	826.6
2001	1,864.1	5	10.1	754.3	21.0	775.3
2002	1,876.6	4	7.1	706.7	20.0	726.7
2003	1,888.1	3	4.9	662.5	19.0	681.5
2004	1,901.2	2	3.4	622.9	18.0	641.0
2005	1,914.3	1	2.3	587.2	17.1	604.3

SOURCE: Canadian Energy Research Institute.

TABLE D.8

MEXICO
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	2,202.4	1,582	3,483.2	2,853.9	360.9	3,214.8
1991	2,280.3	1,500	3,421.6	2,971.7	370.1	3,341.8
1992	2,319.2	1,408	3,264.7	3,079.7	379.4	3,459.1
1993	2,359.8	1,307	3,084.9	3,176.9	389.0	3,565.9
1994	2,388.7	1,202	2,870.7	3,261.8	398.9	3,660.7
1995	2,422.0	1,095	2,651.0	3,334.3	409.0	3,743.3
1996	2,483.1	988	2,453.1	3,395.8	419.3	3,815.1
1997	2,541.0	883	2,243.3	3,445.9	429.9	3,875.8
1998	2,571.9	781	2,009.9	3,483.5	440.8	3,924.3
1999	2,637.3	686	1,810.4	3,510.7	451.9	3,962.6
2000	2,704.0	598	1,615.7	3,527.7	463.4	3,991.1
2001	2,714.5	516	1,399.6	3,533.8	460.8	3,994.6
2002	2,779.7	443	1,230.3	3,531.4	458.2	3,989.6
2003	2,835.8	377	1,069.0	3,521.2	455.6	3,976.8
2004	2,901.0	319	925.1	3,504.0	453.1	3,957.0
2005	2,964.3	268	794.0	3,480.6	450.5	3,931.2

SOURCE: Canadian Energy Research Institute.

TABLE D.9

MALAYSIA/BRUNEI
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	1,143.5	204	233.4	712.1	46.0	758.1
1991	1,152.2	189	218.1	724.2	46.0	770.2
1992	1,156.5	175	201.9	735.4	46.0	781.4
1993	1,161.1	160	186.1	745.3	46.0	791.3
1994	1,164.3	147	170.6	750.9	46.0	796.9
1995	1,168.0	133	155.8	753.1	46.0	799.1
1996	1,174.8	121	142.2	751.4	46.0	797.4
1997	1,181.3	109	129.2	746.6	46.0	792.6
1998	1,184.7	98	116.7	739.0	46.0	785.0
1999	1,192.0	88	105.4	728.9	46.0	774.9
2000	1,199.4	79	95.0	716.6	46.0	762.6
2001	1,200.6	71	84.9	701.9	46.0	747.9
2002	1,207.8	63	76.1	685.9	46.0	731.9
2003	1,214.1	56	68.0	668.2	46.0	714.2
2004	1,221.4	50	60.6	649.6	46.0	695.6
2005	1,228.4	44	54.0	630.3	46.0	676.3

SOURCE: Canadian Energy Research Institute.

TABLE D.10

NORTH SEA
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	2,534.8	297	751.7	3,596.5	260.9	3,857.3
1991	2,604.3	257	669.0	3,695.8	266.6	3,962.4
1992	2,638.9	218	574.3	3,774.8	272.5	4,047.3
1993	2,675.1	180	482.7	3,834.5	278.5	4,113.0
1994	2,700.8	147	396.5	3,755.6	262.1	4,017.7
1995	2,730.5	118	320.9	3,664.3	246.6	3,910.9
1996	2,784.9	93	258.4	3,515.3	232.1	3,747.4
1997	2,836.5	72	205.6	3,365.5	218.4	3,583.9
1998	2,864.0	56	161.2	3,209.9	205.5	3,415.4
1999	2,922.3	43	127.0	3,053.6	193.4	3,246.9
2000	2,981.7	33	99.7	2,894.6	182.0	3,076.6
2001	2,991.0	26	77.0	2,737.6	171.2	2,908.9
2002	3,049.1	20	60.4	2,580.2	161.1	2,741.3
2003	3,099.1	15	47.2	2,426.0	151.6	2,577.6
2004	3,157.2	12	36.9	2,276.9	142.7	2,419.6
2005	3,213.6	9	28.7	2,132.2	134.3	2,266.5

SOURCE: Canadian Energy Research Institute.

TABLE D.11

OTHER AFRICA
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	348.6	524	182.5	35.5	0.0	35.5
1991	352.8	514	181.4	37.1	0.0	37.1
1992	354.9	505	179.1	38.7	0.0	38.7
1993	357.1	495	176.7	40.2	0.0	40.2
1994	358.7	485	173.9	41.8	0.0	41.8
1995	360.4	475	171.1	43.3	0.0	43.3
1996	363.7	464	168.9	44.7	0.0	44.7
1997	366.8	454	166.6	46.2	0.0	46.2
1998	368.5	443	163.4	47.6	0.0	47.6
1999	372.0	433	161.0	48.9	0.0	48.9
2000	375.6	422	158.5	50.3	0.0	50.3
2001	376.2	411	154.6	51.6	0.0	51.6
2002	379.7	400	151.9	52.9	0.0	52.9
2003	382.7	389	148.8	54.1	0.0	54.1
2004	386.2	378	145.9	55.3	0.0	55.3
2005	389.6	366	142.8	56.5	0.0	56.5

SOURCE: Canadian Energy Research Institute.

TABLE D.12

OTHER MIDDLE EAST
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	2,135.1	161	342.9	1,122.4	45.9	1,168.3
1991	2,173.5	156	339.4	1,174.1	47.0	1,221.2
1992	2,192.7	152	332.2	1,222.2	48.2	1,270.4
1993	2,212.7	147	324.8	1,261.5	49.4	1,310.9
1994	2,226.9	142	316.0	1,290.0	50.6	1,340.6
1995	2,243.3	137	307.3	1,311.2	51.9	1,363.2
1996	2,273.4	132	300.1	1,324.4	53.2	1,377.6
1997	2,302.0	127	292.3	1,329.7	54.5	1,384.3
1998	2,317.2	122	282.5	1,329.2	55.9	1,385.1
1999	2,349.4	117	274.6	1,322.8	55.2	1,378.0
2000	2,382.2	112	266.4	1,312.4	54.6	1,366.9
2001	2,387.4	107	254.9	1,298.9	53.9	1,352.8
2002	2,419.5	102	246.4	1,282.5	53.3	1,335.7
2003	2,447.2	97	237.2	1,263.9	52.6	1,315.6
2004	2,479.3	92	228.4	1,241.8	52.0	1,293.8
2005	2,510.5	87	219.3	1,218.9	51.4	1,270.3

SOURCE: Canadian Energy Research Institute.

TABLE D.13

PAKISTAN/INDIA
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	3,578.6	71	253.3	813.9	6.0	819.9
1991	3,607.7	48	172.1	817.4	6.0	823.4
1992	3,622.2	31	111.2	805.4	6.0	811.4
1993	3,637.4	19	70.5	783.0	6.0	789.0
1994	3,648.2	12	44.6	754.3	6.0	760.3
1995	3,660.7	8	28.4	722.1	6.0	728.1
1996	3,683.5	5	18.3	688.0	6.0	694.0
1997	3,705.1	3	11.9	655.5	6.0	661.5
1998	3,716.7	2	7.7	622.4	6.0	628.4
1999	3,741.1	1	5.1	589.0	6.0	595.0
2000	3,766.0	1	3.3	555.7	6.0	561.7
2001	3,769.9	1	2.2	522.6	6.0	528.6
2002	3,794.3	0	1.4	490.0	6.0	496.0
2003	3,815.2	0	1.0	458.0	6.0	464.0
2004	3,839.6	0	0.6	427.7	6.0	433.7
2005	3,863.3	0	0.4	399.1	6.0	405.1

SOURCE: Canadian Energy Research Institute.

TABLE D.14

PERU
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	1,004.7	45	44.7	149.3	0.0	149.3
1991	1,024.5	45	45.6	145.1	0.0	145.1
1992	1,032.9	45	46.0	141.7	0.0	141.7
1993	1,042.5	44	46.3	138.9	0.0	138.9
1994	1,048.5	44	46.4	136.6	0.0	136.6
1995	1,056.2	44	46.5	134.6	0.0	134.6
1996	1,072.5	44	46.9	133.1	0.0	133.1
1997	1,088.1	43	47.2	131.9	0.0	131.9
1998	1,095.6	43	47.1	130.9	0.0	130.9
1999	1,114.2	43	47.4	130.2	0.0	130.2
2000	1,133.1	42	47.6	129.7	0.0	129.7
2001	1,134.7	41	47.0	129.1	0.0	129.1
2002	1,153.9	41	47.0	128.7	0.0	128.7
2003	1,170.2	40	46.9	128.3	0.0	128.3
2004	1,189.3	39	46.8	128.2	0.0	128.2
2005	1,208.5	38	46.5	128.1	0.0	128.1

SOURCE: Canadian Energy Research Institute.

TABLE D.15

TRINIDAD
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	757.3	100	75.7	172.9	0.0	172.9
1991	770.6	99	76.2	176.9	0.0	176.9
1992	777.2	98	75.8	180.6	0.0	180.6
1993	784.1	96	75.3	183.7	0.0	183.7
1994	789.0	94	74.4	186.2	0.0	186.2
1995	794.6	92	73.4	188.2	0.0	188.2
1996	805.0	90	72.6	189.8	0.0	189.8
1997	814.8	88	71.6	190.9	0.0	190.9
1998	820.1	85	70.0	191.4	0.0	191.4
1999	831.1	83	68.8	191.6	0.0	191.6
2000	842.5	80	67.4	191.3	0.0	191.3
2001	844.2	77	65.1	190.5	0.0	190.5
2002	855.3	74	63.5	189.2	0.0	189.2
2003	864.8	71	61.5	187.7	0.0	187.7
2004	875.9	68	59.6	185.9	0.0	185.9
2005	886.6	65	57.6	184.0	0.0	184.0

SOURCE: Canadian Energy Research Institute.

TABLE D.16

UNITED STATES
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	193,413.1	9	1,809.4	7,424.0	1,537.6	8,961.7
1991	204,548.7	9	1,858.9	7,186.4	1,502.3	8,688.7
1992	210,098.7	9	1,850.5	6,983.5	1,467.8	8,451.4
1993	215,908.5	9	1,838.5	6,807.9	1,434.1	8,242.1
1994	220,031.8	8	1,807.2	6,649.3	1,401.2	8,050.5
1995	224,790.1	8	1,776.2	6,504.8	1,369.0	7,873.9
1996	233,526.0	8	1,769.3	6,403.4	1,337.6	7,741.0
1997	241,800.8	7	1,750.2	6,314.0	1,306.9	7,620.8
1998	246,213.5	7	1,697.2	6,235.6	1,276.9	7,512.4
1999	255,554.3	7	1,670.9	6,173.1	1,247.6	7,420.6
2000	265,080.1	6	1,636.6	6,121.8	1,218.9	7,340.7
2001	266,583.4	6	1,549.1	6,062.2	1,190.9	7,253.1
2002	275,899.1	5	1,502.4	6,007.2	1,163.6	7,170.8
2003	283,918.8	5	1,442.2	5,950.8	1,136.9	7,087.7
2004	293,234.2	5	1,382.6	5,892.7	1,110.8	7,003.5
2005	302,285.2	4	1,316.4	5,824.2	1,085.3	6,909.5

SOURCE: Canadian Energy Research Institute.

TABLE D.17

WESTERN EUROPE
DETAILED REGIONAL SUPPLY FORECAST
1990-2005

Year	Drilling Activity (Mft)	Finding Rate (b/ft)	Reserve Additions (MMb)	Actual Crude Oil Production (Mb/d)	NGL Production (Mb/d)	Total Liquids Production (Mb/d)
1990	3,695.8	25	91.6	539.1	40.5	579.6
1991	3,868.9	23	88.1	563.5	42.3	605.8
1992	3,955.2	21	82.2	596.2	44.1	640.3
1993	4,045.6	19	76.4	583.1	41.3	624.4
1994	4,109.7	17	70.2	580.8	38.7	619.5
1995	4,183.7	15	64.3	557.1	36.3	593.2
1996	4,319.5	14	59.5	533.7	34.0	567.7
1997	4,448.1	12	54.6	511.2	31.8	543.0
1998	4,516.7	11	49.2	488.7	29.8	518.5
1999	4,662.0	10	44.8	467.0	27.9	494.9
2000	4,810.1	8	40.6	445.1	26.2	471.3
2001	4,833.5	7	35.6	423.5	24.5	448.0
2002	4,978.3	6	32.0	401.5	23.0	424.5
2003	5,103.0	6	28.4	380.3	21.5	401.8
2004	5,247.8	5	25.2	359.0	20.2	379.2
2005	5,388.5	4	22.2	338.6	18.9	357.5

SOURCE: Canadian Energy Research Institute.

APPENDIX E

SUMMARY RESULTS: ALTERNATIVE SCENARIOS

TABLE E.1

MARKET SUMMARY
HIGH NON-OPEC RESOURCE SCENARIO
1990-2005

Year	Price ($1989 U.S.)	World Demand (MMb/d)	World Supply (MMb/d)	Non-CPE Demand (MMb/d)	Non-CPE Supply (MMb/d)	Net CPE Exports (MMb/d)	OPEC Production (MMb/d)
1990	19.40	67.70	67.70	53.71	51.53	2.18	22.00
1991	20.10	68.69	68.69	54.51	52.53	1.98	22.60
1992	20.00	69.79	69.79	55.41	53.58	1.83	23.20
1993	20.15	70.90	70.90	56.32	54.74	1.58	24.00
1994	20.40	72.01	72.05	57.20	55.86	1.38	24.90
1995	20.15	73.27	73.27	58.22	57.04	1.19	25.90
1996	20.45	74.47	74.47	59.18	58.19	1.00	26.90
1997	20.90	75.58	75.58	60.06	59.27	0.79	27.90
1998	20.95	76.78	76.78	61.02	60.43	0.59	29.00
1999	21.40	77.90	77.90	61.91	61.56	0.35	30.10
2000	22.00	78.92	78.92	62.69	62.69	0.00	31.20
2001	21.85	80.12	80.12	63.65	63.65	0.00	32.20
2002	22.30	81.31	81.31	64.60	64.60	0.00	33.20
2003	22.70	82.50	82.52	65.53	65.55	0.00	34.20
2004	23.05	83.71	83.71	66.48	66.48	0.00	35.20
2005	23.55	84.88	84.88	67.40	67.40	0.00	36.20

SOURCE: Canadian Energy Research Institute, January 1990.

TABLE E.2a

MARKET SUMMARY
NEAR-TERM OPEC PRICE GAIN SCENARIO
1990-2005

Year	Price ($1989 U.S.)	World Demand (MMb/d)	World Supply (MMb/d)	Non-CPE Demand (MMb/d)	Non-CPE Supply (MMb/d)	OPEC Production (MMb/d)
1990	20.85	67.02	67.02	53.03	50.85	22.00
1991	23.65	67.21	67.21	53.03	51.05	22.00
1992	24.70	67.45	67.45	53.07	51.24	22.00
1993	26.45	67.52	67.57	52.94	51.41	22.00
1994	28.00	67.58	67.60	52.78	51.41	22.00
1995	29.73	67.60	67.65	52.56	51.42	22.00
1996	27.20	68.47	68.47	53.18	52.19	23.00
1997	28.10	69.23	69.23	53.71	52.92	24.00
1998	28.90	69.95	70.12	54.19	53.77	25.00
1999	29.10	70.76	70.76	54.78	54.42	26.00
2000	31.10	71.29	71.29	55.06	55.06	27.00
2001	30.70	72.09	72.09	55.62	55.62	28.00
2002	31.70	72.87	72.87	56.15	56.16	29.00
2003	31.95	73.78	73.78	56.80	56.81	30.00
2004	33.30	74.55	74.55	57.32	57.32	31.00
2005	34.20	75.31	75.31	57.83	57.83	32.00

SOURCE: Canadian Energy Research Institute, January 1990.

TABLE E.2b

MARKET SUMMARY
NEAR-TERM OPEC PRODUCTION GAIN SCENARIO
1990-2005

Year	Price ($1989 U.S.)	World Demand (MMb/d)	World Supply (MMb/d)	Non-CPE Demand (MMb/d)	Non-CPE Supply (MMb/d)	OPEC Production (MMb/d)
1990	18.00	67.95	67.95	53.96	51.78	23.08
1991	18.00	69.60	69.60	55.42	53.44	24.87
1992	18.00	71.17	71.17	56.80	54.96	26.54
1993	18.00	72.68	72.68	58.10	56.52	28.33
1994	18.00	74.17	74.17	59.36	57.98	30.19
1995	18.00	75.64	75.64	60.60	53.41	32.05
1996	18.00	77.10	77.10	61.82	60.82	33.89
1997	20.20	77.77	77.77	62.25	61.46	34.87
1998	22.30	77.92	77.92	62.17	61.57	35.21
1999	24.50	77.76	77.76	61.77	61.42	35.25
2000	26.65	77.42	77.42	61.20	61.09	35.03
2001	28.35	76.83	76.83	60.54	60.44	34.48
2002	29.20	76.37	76.37	60.07	59.96	34.11
2003	29.90	76.06	76.06	59.75	59.65	34.00
2004	30.70	75.81	75.81	59.50	59.40	33.94
2005	31.60	75.58	75.59	59.27	59.27	33.97

SOURCE: Canadian Energy Research Institute, January 1990.

TABLE E.3

MARKET SUMMARY
ENVIRONMENTAL INITIATIVES SCENARIO
1990-2005

Year	Price ($1989 U.S.)	World Demand (MMb/d)	World Supply (MMb/d)	Non-CPE Demand (MMb/d)	Non-CPE Supply (MMb/d)	Net CPE Exports (MMb/d)	OPEC Production (MMb/d)
1990	20.40	66.99	66.99	53.00	50.82	2.18	22.00
1991	20.90	67.65	67.65	53.48	51.49	1.98	22.60
1992	20.85	68.32	68.32	53.94	52.11	1.83	23.20
1993	20.85	68.98	69.02	54.40	52.86	1.58	24.00
1994	20.70	69.69	69.69	54.89	53.50	1.38	24.90
1995	20.30	70.40	70.40	55.36	54.17	1.19	25.90
1996	20.20	71.04	71.04	55.76	54.76	1.00	26.90
1997	20.05	71.64	71.64	56.12	55.33	0.79	27.90
1998	19.70	72.32	72.32	56.56	55.97	0.59	29.00
1999	19.70	72.94	72.94	56.95	56.60	0.35	30.10
2000	20.05	73.46	73.46	57.23	57.23	0.00	31.20
2001	19.50	74.21	74.21	57.74	57.74	0.00	32.20
2002	19.50	74.96	74.96	58.24	58.25	0.00	33.20
2003	19.55	75.74	75.74	58.77	58.77	0.00	34.20
2004	19.60	76.54	76.54	59.32	59.31	0.00	35.20
2005	19.75	77.35	77.35	59.87	59.87	0.00	36.20

SOURCE: Canadian Energy Research Institute, January 1990.

TABLE E.4

MARKET SUMMARY
CENTRALLY PLANNED ECONOMIES SCENARIO
1990-2005

Year	Price ($1989 U.S.)	World Demand (MMb/d)	World Supply (MMb/d)	Non-CPE Demand (MMb/d)	Non-CPE Supply (MMb/d)	Net CPE Exports (MMb/d)	OPEC Production (MMb/d)
1990	20.85	67.02	67.02	53.03	50.85	2.18	22.00
1991	21.85	67.72	67.72	53.54	51.56	1.98	22.60
1992	22.30	68.45	68.45	54.07	52.24	1.83	23.20
1993	22.90	69.19	69.23	54.59	53.07	1.56	24.00
1994	23.30	69.99	70.01	55.14	53.82	1.34	24.90
1995	23.70	70.83	70.83	55.71	54.60	1.11	25.90
1996	24.60	71.61	71.61	56.18	55.33	0.85	26.90
1997	24.50	72.57	72.57	56.85	56.00	0.85	27.90
1998	24.70	73.61	73.61	57.57	56.73	0.84	29.00
1999	25.35	74.59	74.64	58.24	57.50	0.79	30.10
2000	26.00	75.53	75.53	58.86	58.23	0.63	31.20
2001	25.95	76.66	76.66	59.65	58.83	0.82	32.20
2002	26.55	77.80	77.80	60.42	59.40	1.02	33.20
2003	27.00	78.96	78.96	61.21	59.98	1.23	34.20
2004	27.60	80.13	80.13	61.99	60.54	1.45	35.20
2005	28.10	81.31	81.31	62.77	61.10	1.67	36.20

SOURCE: Canadian Energy Research Institute, January 1990.

GLOSSARY[1]

API GRAVITY: the measure of gravity (weight) of liquid petroleum products, derived from specific gravity according to the following equation.

$$\text{API Gravity} = \frac{141.5}{\text{specific gravity}} - 131.5$$

where specific gravity is the ratio of the weight of a given volume of a substance to the weight of a "standard" substance, both at the same temperature.

API gravity is expressed in degrees, such that a specific gravity of 1.0 is equivalent to 10° API. The API scale assigns an API gravity of 10° to pure water.

BITUMEN: Viscous mixture of hydrocarbons, which occurs naturally but is not commercially recoverable by standard methods. Also hydrocarbon residue from distillation of some crude oils.

CARTEL: An organization of producers who agree to act as a single seller, thus limiting competition among themselves, in order to maximize joint profits.

CATALYST: A substance that helps to initiate a chemical reaction and enables it to proceed under less severe conditions (for example, at a lower temperature or pressure), but remains unchanged itself.

COAL LIQUEFACTION: The production of a synthetic crude oil or related liquid fuel from coal.

COKE: Solid carbon residue of coal or crude oil that remains after volatile hydrocarbons have been removed by distillation or cracking. Can be used as a feedstock for the manufacture of synthesis gas.

CONDENSATE: A mixture mainly of pentanes and heavier hydrocarbons that is recoverable at a well from an underground reservoir, and which is gaseous in its reservoir state but which condenses to a liquid at atmospheric pressure and temperature. Condensate is often included with "crude oil."

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[1] Excerpts from National Energy Board, *Canadian Energy Supply and Demand 1987-2005*; House of Commons Standing Committee on Energy Mines and Resouces, *Oil Scarcity or Security*, October 1987; Energy, Mines and Resources Canada, *Future Transportation Fuels: Synthetic Fuels* (Ottawa, Ontario: Supply and Services Canada, 1987); and Canadian Energy Research Institute.

CONSTANT DOLLARS: Value of a currency expressed in terms of the purchasing power of the currency or, alternatively, the ability of the currency to command real goods and services. It can be calculated as money income or expenditures deflated by a price index. Thus a world oil price forecast expressed in constant $1989 U.S. per barrel projects the ability of a barrel of crude oil to command real goods and services in exchange, abstracting from general price inflation over the forecast period.

(CONVENTIONAL) CRUDE OIL: A mixture mainly of pentanes and heavier hydrocarbons that is recoverable at a well from an underground reservoir, and which is liquid at atmospheric pressure and temperature.

CRUDE BITUMEN: Very heavy crude oil or tar consisting of a naturally occurring viscous mixture, mainly of hydrocarbons heavier than pentane, that may contain sulphur compounds and other minerals, and that in its natural viscous state is not recoverable at a commercial rate through a well.

CRUDE OIL AND EQUIVALENT HYDROCARBONS: Sometimes referred to as Crude Oil and Equivalent. Includes light and heavy crude oil, pentanes plus, bitumen and synthetic crude oil.

DIESEL FUEL: High-grade fuel oil suitable for use in compression ignition engines. Available in different grades; regular grade has a cetane number of 40-45 and premium grade of 45-50.

DIRECT LIQUEFACTION: Process of obtaining liquid fuel from coal. Hydrogen is added to the feedstock, which is dispersed in a slurry of coal-derived oil.

DISTILLATION: Process of heating a liquid to the boiling point and collecting and condensing the resulting vapour.

ESTABLISHED RESERVES (CANADA): Those reserves recoverable under current technology and present and anticipated economic conditions, specifically proved by drilling, testing or production, plus that judgement portion of contiguous recoverable reserves that are interpreted to exist, from geological, geophysical or similar information, with reasonable certainty.

EXPERIMENTAL CRUDE OIL: Crude oil produced from pilot projects designed to investigate new recovery techniques.

FIELD: May refer to a certain geographical area from which petroleum is produced or to a particular underground producing zone. A field may contain one or more pools linked by some common element, such as lying along the same trend or being a product of a common geographical disturbance.

FOSSIL FUELS: Combustible geologic deposits of biogenic hydrocarbons. These deposits include crude oil, natural gas, oil shales, oil sands and coal.

FRACTIONAL DISTILLATION: Product of separating a mixture of liquids of different volatility, e.g., crude oil, into its various components by applying heat and then condensing each vapour as it is collected.

FUEL EFFICIENCY (BURNER TIP EFFICIENCY): The ratio of the useful output energy which results when a fuel is burned, to the theoretical input energy content of the fuel. Fuel efficiency for a heating fuel is less than 100 percent to the extent that heated air is used in combustion and to the extent that exhaust venting is necessary. In other applications, fuel efficiencies are less that 100 percent partly because of waste heat generation.

GASIFICATION: Production of methane from coal or biomass by heating the feedstock to high temperatures under high pressure in a restricted amount of oxygen.

GASOLINE: Refined mixture of volatile, petroleum-derived hydrocarbon liquids with octane numbers ranging from 60 to above 100; used as a fuel for spark ignition engines.

GROSS DOMESTIC PRODUCT (GDP): The sum of all values added in an economy or, what is the same thing, the values of all final goods produced in the economy.

HEAVY CRUDE OIL: Crude oil with high viscosity and high boiling point, recoverable only to a limited extent by standard techniques. Oil from deposits intermediate between oil sands and conventional crude oil. Flows slowly or not at all under normal conditions.

HEAVY FUEL OIL: Heavy fuel oil includes bunker fuel oils (No. 5 and No. 6 fuel oils) and industrial fuel oil (No. 4 fuel oil).

HYDROCARBONS: Any organic compounds--solid, liquid or gaseous--consisting only of the elements carbon and hydrogen. Crude oil, natural gas and coal are essentially mixtures of hydrocarbons of varying degrees of complexity and containing varying amounts of impurities such as sulphur, nitrogen, oxygen, helium and metallic elements.

HYDROCRACKING: Refining process for splitting heavy hydrocarbons into lighter fractions by adding extra hydrogen under high pressure with the aid of an acid catalyst.

INDIRECT LIQUEFACTION: Production of liquid fuels from coal via an intermediate process of gasification.

IN-SITU RECOVERY: The process of recovering crude bitumen from oil sands other than by surface mining.

LIGHT CRUDE OIL: A term applied to crude oil having a lower density and which yields relatively high proportions of gasoline, naphtha and kerosene fractions.

LIGHT FUEL OIL: The term light fuel refers to furnace fuel oil (No. 2 fuel oil), kerosene and stove oil (No. 1 fuel oil). The major volume of light fuel oil used in Canada is furnace fuel oil.

LIQUEFIED PETROLEUM GASES (LPG): A subgroup of the natural gas liquids, consisting principally of propane and butanes, obtained from crude oil and natural gas production and also as byproducts of refining. Compressed to liquid form for storage and transportation and used as a fuel.

MEDIUM CRUDE OIL: Crude oil intermediate in viscosity between heavy and light crude oil.

MIDDLE DISTILLATES: The range of refined petroleum products which includes kerosene, stove oil, diesel fuel, and light fuel oil.

NAPHTHA: Petroleum fraction with boiling range of 70°C to 200°C. Octane number is too low for direct use as gasoline. A primary feedstock for the production of petrochemicals.

NATURAL GAS LIQUIDS (NGL): The hydrocarbons ethane, propane, butane, and pentanes plus or a combination thereof.

OCTANE NUMBER: An arbitrary value that indicates the anti-knock quality, or grade, of a gasoline, i.e., provides a measure of the resistance of the fuel to premature ignition. The proportion of iso-octane (octane number 100) in the mixture indicates the octane number of the gasoline blend. Available gasoline blends usually range in octane number from 92 to 100.

OIL: A combustible liquid generally considered to have been formed by geochemical processes acting on the remains of organisms buried in the geologic past. Although oil basically consists of only two elements, carbon and hydrogen, it is characterized by an enormously complex variety of molecular structures - no two crude oils from different sources are identical. Despite this almost unlimited complexity, most crude oils contain 84 percent to 87 percent carbon by weight and 11 percent to 14 percent hydrogen.

In addition to carbon and hydrogen, there are small amounts of other elements present, typically in amounts aggregating less than 3 percent by weight of the oil. Sulphur, nitrogen, and oxygen are the principal "contaminants," although traces of sodium chloride, phosphorus and heavy metals such as vanadium and nickel are common. Heavy oil and natural asphalt may have a sulphur content of 5 percent or more.

The conversion of organic material contained in sediments into petroleum is a function of temperature (in turn related to depth of burial) and time.

Deeper burial by continuing sedimentation, increasing temperatures, and advancing geologic age result in the mature state of petroleum formation during which the full range of petroleum compounds is produced from kerogen and other precursors by thermal degradation and cracking (the process by which heavy hydrocarbon molecules are broken up into lighter molecules). Depending on the amount and type of organic matter, oil generation occurs during the mature stage at depths of about 760 to 4,880 metres (2,500 to 16,000 feet) at temperatures between 65° and 150°C. this special environment is called the "oil window." In areas of higher than normal geothermal gradient (increase in temperature with depth), the oil window exists at shallower depths in younger sediments but is narrower. Maximum oil generation occurs from depths of 2,000 to 2,900 metres. Below 2,900 metres primarily wet gas, a type of gas containing liquid hydrocarbons known as natural gas liquids, is formed.

At the end of the mature stage and at depths greater than about 4,900 metres (16,075 feet), depending on the geothermal gradient, crude oil becomes unstable and the main hydrocarbon product is dry gas (methane). At sediment temperatures greater than about 250°C (482°F), hydrocarbons cease to be generated from organic matter. Depending on its geologic history then, a sedimentary formation may be oil prone, gas prone, both or neither.

Oils are usually characterized by their API gravity, on a scale adopted by the American Petroleum Institute to measure the specific gravity of crude oils. This scale arbitrarily assigns an API gravity of 10° to pure water. Oils lighter than water have an API gravity greater than 10°; those heavier than water have a value less than 10°.

OIL SANDS: Deposits of sand or sandstone, or other sedimentary rocks containing crude bitumen which is too viscous to be recovered through a conventional well.

OIL SHALE: A kerogen-bearing, brown or black shale that will yield gaseous or liquid hydrocarbons on distillation.

PERMEABILITY: A measure of the capacity of a reservoir rock to transmit fluids.

PETROLEUM: A Latin derivative literally meaning "rock oil" and often defined as naturally occurring liquid hydrocarbons. Sometimes the definition is extended to include refined products in the liquid state. In common industry usage, petroleum has come to mean any hydrocarbon mixture that can be produced through a drill pipe, including natural gas, condensate and crude oil.

POOL: A natural underground reservoir containing an accumulation of oil and/or natural gas separated, or appearing to be separated, from any other such accumulation.

POSSIBLE RESERVES: Reserves from these areas whose oil bearing has not yet been established by production tests, but for which data collected to date favour the presence and extractability of crude oil.

PROBABLE RESERVES: Known productive reserves in discovered fields expected to respond to improved (enhanced) recovery techniques.

PRODUCTIVE CAPACITY: The estimated rate at which natural gas, crude oil or crude bitumen can be produced from a well, pool or other entity, unrestricted by demand, having regard to reservoir characteristics, economic considerations, regulatory limitations, the feasibility of infill drilling and/or additional production facilities, the existence of gathering, processing and transmission facilities, and losses due to scheduled facility maintenance and potential for mechanical breakdown.

PROVED RESERVES: The estimated quantities of hydrocarbon resource, at a specific date, which analysis of geological and engineering data demonstrates with reasonable certainty, to be recoverable in the future from known reservoirs under the economic and operational conditions of the same date.

REFINING: Process of heating crude oil until it separates into its chemical components, which are then processed into useable products.

RESERVES: That portion of the resource that has been discovered, of which part is recoverable under current economic and technical circumstances and part is not.

RESERVES ADDITIONS: Incremental changes to established reserves resulting from the discovery of new pools and reserves appreciation.

RESERVES APPRECIATION: Incremental change in established reserves resulting from extensions to existing pools and/or revisions to previous reserves estimates.

RESERVES LIFE INDEX: Remaining reserves divided by annual production.

RESERVOIR: A porous, permeable sedimentary rock containing commercial quantities of oil and/or natural gas.

RESOURCE: All oil and gas accumulations either known or inferred to exist. That portion of the resource base which has been found is referred to as discovered resources or reserves. That portion of the resource base which is inferred to exist but not yet discovered is known as undiscovered resources or potential resources.

SHALE OIL: Oil obtained from the treatment of kerogen contained in oil shale. No shale oil is produced in Canada at the present time, although oil shales are found in various regions of the country.

SPOT PRICES: Prices established on secondary or spot markets for immediate product delivery. Under normal market conditions, spot prices will carry a premium over contract prices associated with the short-term and unpredictable nature of spot purchases.

Spot prices respond more rapidly than list or contract prices to changes in short-term market conditions and are often used as a barometer of market developments. However, spot prices are also susceptible to the influence of transitory, psychological factors operating on the market, making them unreliable for medium-term planning purposes.

SYNTHETIC FUELS: Liquid or gaseous fuels, similar to those made from light crude oil, produced from bitumen, heavy oil, natural gas, coal or biomass.

SYNTHETIC CRUDE OIL (Syncrude): As commonly understood in Canada, a mixture mainly of pentanes and heavier hydrocarbons that is derived from crude bitumen through the addition of hydrogen or the deletion of carbon, and which is liquid at atmospheric pressure and temperature. Syncrude also includes oil obtained from oil shale or coal.

TAR SANDS: Sands impregnated with a heavy crude oil, tar-like in consistency, that is too viscous to permit recovery by natural flowage into wells. This term used to be applied to the bitumen deposits of Alberta but has largely been supplanted by "oil sands" in Canadian usage. In the United States and elsewhere, the term "tar sands" is still in common use.

ULTIMATE POTENTIAL RESERVES: Estimate of the initial established reserves which will have become developed in an area by the time all exploratory and development activity has ceased, having regard to the geological prospects of that area and anticipated technology and economic conditions.

Ultimate potential includes cumulative production, remaining established reserves, and future reserves additions through extensions of and revisions to existing pools and discovery of new pools.

UPGRADING: Conversion of bitumen or heavy oil into synthetic crude oil.

VISCOSITY: Measure of a liquid's resistance to flow at a specified temperature. A higher viscosity measure indicates a lower flow rate under a given set of conditions.

WEST TEXAS INTERMEDIATE (WTI): A light crude oil (32° API) produced in the south-central United States and marketed in the Midwest (Chicago) region. WTI has played the role of a benchmark crude for pricing of United States and Canadian light/medium crude oil output. However, the relatively small annual production volumes of WTI crude and the impact of regional supply/demand pressures on WTI price have raised concerns over its appropriateness as a representative world oil price marker.

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